THE STRUCTURE

OF

THE WOOL FIBRE

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THE STRUCTURE

OF

THE WOOL FIBRE

AND ITS RELATION TO THE USE OF WOOL
FOR TECHNICAL PURPOSES

BY

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OF DYERS AND COLOURISTS

WITH NUMEROUS COLOURED AND OTHER ILLUSTRATIONS

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PREFACE

In the spring of 1880, when technical education was beginning seriously to occupy attention in this country, I was requested by the Council of the Bradford Technical College, then recently founded, to deliver a series of lectures on the "Structure of the Cotton Fibre in its relation to Technical Applications," and these were given in the large lecture theatre of the Bradford Mechanics' Institute, as the buildings of the Technical College were not completed. These lectures were printed in a volume issued by myself in 1881, and followed by a second edition in 1882.

In 1884 I delivered a similar course of lectures on the "Structure of the Wool Fibre in its relation to Technical Applications," which were delivered in Bradford, Huddersfield, and afterwards in a *résumé* at Nottingham University College, and published in the spring of 1885. Both these books had a large sale, and were accepted as the standard works on the subject, alike in this country, America, and on the Continent. They were, I believe, with the exception of a few detached papers published in scientific journals,

the first serious attempt to place our knowledge of these fibres upon a thoroughly scientific basis.

When, in 1886, I was selected by the Royal Commission of the Indian and Colonial Exhibition to report on the wools there exhibited, I had the opportunity of examining probably the finest collection of wools which had up to that time been gathered together, and made extensive notes for future reference.

The books above named have long been out of print, and although many works have since appeared dealing with the same subject, my work and results have been largely embodied in them all, either acknowledged or unacknowledged, and the sketches of the fibres which I made have been universally accepted as authoritative.

I have had many requests, and especially within the last twelve months, to revise them and bring them up to date. Fortunately, during the time since they were published I have made a large number of experiments and observations and sketches, and when the present publishers accepted my offer to write for them a monograph on the subject, to be included in this series of their technological handbooks, I felt the opportunity was not to be neglected. The present volume, therefore, forms the second of three books on "the cotton, wool, silk and other allied fibres in their relation to technical applications," and the third will follow as early as possible.

This work will, so far as I can make it, cover the whole ground in relation to the wool fibre.

I hesitated for some time before deciding whether the illustrations should be photographic or graphic, but decided in favour of the latter, as the typical distinctions which I wish to emphasise are only to be found in single fibres that are mixed in the fleece with thousands of others, which photography cannot select or show to the same advantage, although clearly perceptible to the eye, and which distinctions are best represented diagrammatically for educational purposes,—just as a painted portrait can be made more characteristic than the most artistic photograph, as the individuality can be better brought out.

The scope of the work is the fibre itself, and its relation to the various processes of manufacture, both mechanical and chemical, rather than the methods employed in manufacture, my object being to summarise the distinctive character of the raw material, upon the nature of which all the changes in the process of manufacture must be based if the best results are to be obtained. Hence I deal not with the machinery but with the raw material which it treats, and have to assist me in this inquiry an extensive knowledge of the machinery used, as having been practically engaged, on a large scale, in both the cotton and worsted spinning industries. Thus when looking at the fibre from the mechanical side of the question, I examine it as I should any other structural material, from an engineering standpoint, so as to determine what its different qualities are, and how they may be best

utilised in connection with any method of manufacture, so as to enable those who wish to manipulate it to avoid such errors as in structural iron-work would be made if cast-iron was to be employed to resist tension and wrought-iron compression. So also, when dealing with the question of dyeing, my inquiry was confined to the method in which the fibre lends itself to the reception of the dye, and the way in which the dye-stuff is received by the fibre rather than the methods employed to dye it, although the limitations of these methods are always taken into consideration. I have endeavoured also to embody, so far as I was able, the researches of others in the same direction as my own, and have, wherever I could trace these sources, acknowledged them by reference. I am indebted to Mr. James M'P. Miller, B.Sc., in reference to reading the proofs of the chapter on dyeing, and to Mr. A. Hoegger, Chairman of the British Cotton and Wool Dyers' Association, Ltd., who supplied me with complete ranges of samples of grey and dyed yarns. I have also to thank the publishers, printers, and artists, who have combined to make the work a success, and especially in the faithful reproductions of my drawings; which will render it additionally interesting to the readers.

I give a list on page xx of the various works which I have consulted during the last few years.

Although this work does not profess to be exhaustive, it is, nevertheless, so far as I can make it, a *résumé* of our knowledge on the subject up to the present day, and I

hope its perusal may stimulate further research in those directions in which our information is yet incomplete. With this wish I send it forth as my contribution to the materials which must form the base of a higher technological knowledge, upon which the commercial prosperity of the British people must in the future depend, and subscribe myself

F. H. BOWMAN.

MANCHESTER, *September* 1908.

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LIST OF BOOKS CONSULTED BY THE AUTHOR

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CHAPTER I

INTRODUCTION

The advantage of Technical Education is now universally recognised, and all our towns and cities are equipping themselves with large technical schools and colleges, where a staff of highly trained teachers are expounding the principles of scientific knowledge, upon which in the future all our manufacturing and other industries must be based if this country is to hold its own in the race for commercial supremacy. The rapid strides which are being made by our competitors on the Continent of Europe, and in the United States of America, and the readiness with which they are calling into requisition all the resources which modern scientific investigation and research have placed at their disposal, is an additional reason why every effort should be put forth to enable the young men of this country to enjoy equal advantages.

There is no doubt but that during the middle of the last century the unparalleled advantage enjoyed by Germany, in the possession of a complete system of graduated education, and the foundation of large and well-equipped polytechnical institutions, with research laboratories both for physical and chemical instruction,

laid the foundation of the surprising development of the trade and commerce of that country, and which especially has enabled Germany to take a leading position in the steel and chemical industries, and all those which depend for their success upon a knowledge of exact science. Fortunately, these advantages are now to be obtained in this country also, and, although somewhat late in the field, we are now possessed of similar institutions which are second to none, and which, if full advantage is taken of them, will enable our countrymen, who are not behind other nations either in intellectual attainments, energy, determination, or inventive faculties, to keep abreast of the times, and carry into our workshops and manufactories the knowledge and skill which will not only enable us to maintain our position but to take the lead in every industry for which we are fitted, whether it be in articles of utility or taste.

Another element must also now be taken into consideration, viz. the awakening of the Eastern nations, led by the Japanese, who, fully aware of the advantages which knowledge has given to the Western nations whether in the arts of war or peace, have presented a wonderful renaissance, and within the space of two generations have sprung from a comparatively humble position to one of deserved recognition, and taken their place amongst the comity of nations. Their skill in art and metallurgy, especially in bronze casting and handicraft manipulation, such as the production of glazes, and the use of enamels in ornamental work and pottery, have always been remarkable, and they are now actively entering into competition with the Western world in almost every branch of commerce, such as cotton spinning, weaving, and various branches of engineering, and will contest with

us in all the markets of the East. The same may also be said of the industrial activity which is now beginning to stir the latent energies of China, and which, with its enormous, docile, and industrious population, will before very long certainly enter the competition for her own market, with all the advantages of our most recent improvements in machinery, and with the cheapest labour in the world. Fortunately for us, our rivals, at any rate in Europe, so far as textile manufactures are concerned, have to work with the same raw materials as ourselves, and our insular position which gives us a sea-board on every side, and the fact that we are, thanks to our Free Trade policy, the great ocean carriers of the world, makes our country the great central emporium through which the raw materials for the world's use must pass, and gives us facilities for comparison and selection which are enjoyed by no other nation. In addition to this, "the island gem set in the silver sea," enswathed by the ocean waters, gives us a climate more equitable than the continental nations, and fosters the energy which might otherwise be enervated and paralysed by wider ranges of temperature. The fact that this country is the great market of the world's raw material enabled such men as the late Sir Titus Salt and Lord Masham, both of Bradford (Yorkshire), to secure supplies of alpaca wool and silk waste, which could not be used by others, and upon which they founded large and flourishing industries; and it is not improbable that in the future analogous opportunities may be afforded which the higher technical knowledge and skill that is now available may be able to turn to good account.

In considering the general principles upon which successful industrial progress must be made, it is easy to see that we must, as a first instance, make ourselves

thoroughly masters of the great principles and laws that underlie all processes and reactions, whether mechanical or chemical, which the raw material must undergo in its transformation into the finished article.

Unless this is done we can never expect to attain the best results, because we shall be sure to treat the raw material either too little or too much, or subject it to processes which are either unnecessary or unfit for obtaining the object which we have in view.

To gain this end it is quite essential that, at the very outset of all our textile manufactures, we must have a clear and distinct knowledge of the true nature of the raw material upon which we have to work. No comprehension of general principles can obviate the necessity for this knowledge, because this alone can enable us to select the raw material that will best serve the purpose which we have in view, and then enable us to select our various transforming processes, so as to suit the raw material, by bringing into play all its peculiar properties without injury or detriment to its structure.

Attention to this will always enable us also to use the least expensive raw material for the purpose, because, if the material is not treated exactly as it should be in our mechanical and chemical operations, we shall be obliged to use a better raw material than we otherwise should, and so give an advantage to competitors who have a better knowledge than ourselves. The author has known of several instances where, in consequence of a want of chemical knowledge, the colour of a textile fibre was deteriorated in one process, and to overcome this a much better grade of raw material had to be employed, which, in consequence of its not containing a certain constituent, did not darken; while another man, who possessed the necessary knowledge

to prevent the fibre from darkening, could use the lower grade which otherwise possessed all the qualifications required.

The neglect of these precautions, which have in most instances resulted from a want of knowledge, has in the past been a source of great annoyance and loss to the trade, and numerous cases have arisen in the worsted trade where the lustre of the wool has been destroyed by the chemical means used to cleanse it, or the staple broken and rendered less in strength and uniformity by the use of imperfect machinery, or imperfect setting of the machinery through which it was passed. Nor is this all, for it frequently happens that the raw material may be spoilt at the very outset and rendered less fit for manufacture, as in the case of saw-ginning in the cotton, or the neglect of the farmer in the care of his flock, or the injudicious use of detrimental sheep-dips and the use of tar or other smearing material, even before it comes into the hands of the manufacturer. Even the wrapping up of the fleece when in a damp condition may lead to tendering of the wool; or folding it up in such a manner that the best parts of the wool come in contact with those where natural staining has occurred may render it unsuitable for certain purposes and less valuable to the manufacturer. Then, when it comes into his hands it frequently happens that the means employed in some of the earlier stages of the manufacture are absolutely detrimental to those which follow after, and which render it quite impossible to attain the results desired, at any rate in the best possible manner. It is well known, for example, that the spinner and weaver, who are usually quite distinct from the dyer and finisher, very seldom know or consider the processes to which the yarn or cloth will be subjected during the dyeing or

finishing process, and hence it frequently happens, as a result of this want of co-ordination, that the latter have to remove defects which might be avoided by care and forethought in the earlier stages of manufacture.

On this point the author need only instance such a case as the result of the influence of temperature on the wool fibre, which we shall afterwards see is a very important matter in determining both the after-strength and lustre of the wool as well as the power which the fibre possesses to receive the dye. In bygone days the thermometer was seldom called into requisition, in the washing process, to determine the heat of the water. Usually it was considered quite sufficient to guess, the heat by immersion of the hand or the haphazard turning in of the steam, a process which, between two different conditions of the body or two different individuals, will not be the same within a very much wider range than any person would believe possible without trying the experiment.

Take another case, viz. the use of oil, after the washing of the wool has taken place, in the process of combing, carding, or spinning, where the yarn is afterwards to be used for the production of fabrics which have to be dyed into light and delicate shades, and requiring an even distribution over the whole surface, as well as where the wool is required to retain its soft and pliable condition. One of the secrets of the great success of the French dyers in certain classes of dress goods arises from the fact that, after the wool has been carefully washed with the right kind of feeding soap, it is afterwards worked dry and without the use of any artificial oiling, and thus the natural condition of the fibre is retained, and the surface of the fibre and its constituent cells are better fitted both for the preparatory cleansing and after-dyeing process.

For the most perfect manufacture there must be an intelligent understanding of every process, and the co-ordination of each to the after-treatment of the fibre, so that every step will be a step in the right direction, and each process, whether mechanical or chemical, while perfectly performing its appointed function, not in any way interfering with any which follow it.

It may seem at first sight as if this was a comparatively easy thing to accomplish, and one which a very little practice would enable us to settle in such a way that very few mistakes would be made. Experience, however, teaches us otherwise, and it would not be difficult to instance very many cases where up to a recent period, and indeed in some cases even now, in our process of manufacture we have to undo or at any rate put right in a subsequent process what has been put wrong in a former one. For example, it is often found in the spinning of yarn that with the desire to produce solid bobbins, in the preparing machinery, an excessive twist is put into the rovings, which in the spinning prevents the drawing out of the fibres, and thus causes serious breakage in the raw material and irregularity and roughness in the yarn which can never afterwards be removed. This excessive twist is often rendered necessary because of an improper adaptation of the size and weight of the preparing bobbin to the quality and counts of the yarn to be wourd on to it, or the endeavour to spin on the machinery counts for which it was not adapted. As another instance in a different department, the author had placed in his hands a sample of wool that originally had a high lustre, but which was almost entirely removed from the yarn during the process of manufacture and before it was finished, in consequence of the improper treatment in the washing of

the wool, and several ingenious devices were called into requisition to endeavour to restore the lustre, without any satisfactory result.

The same wool in the hands of another manufacturer, only a short distance away, presented a very different appearance, and came up in the yarn bright and shining; but even in this case there is no doubt that by the use of a different liquor in washing, and a proper regulation of the temperature, a still better result might have been attained.

Perfection in manufacture is indeed only possible when the best possible results are attained in each stage of the progress, and to do this each process must be worked out with the most careful detail in every part, and with constant and consistent reference to the end desired, and throughout the whole there must be constant vigilance to see that the best possible is always being achieved.

As a first principle it may be laid down that the raw material must be suited for the purpose to which it is to be employed; and frequently it happens that through want of knowledge in this respect serious blunders are made, and materials used are not those best adapted to the purpose. Thus much of the failures in the use of such a fibre as that furnished by the ramie or China grass has resulted because it has been employed for purposes for which it was entirely unfitted as a result of its mechanical structure, although as regards its high lustre it might have been otherwise used, the fibres lacking the necessary elasticity and accommodation to flexure as compared with cotton or silk.

The investigation of the principles of structural economy, that is, of the fact that the same weight of material may be made to stand varying degrees of stress

depending upon the method in which the material is disposed in the structure, and thus withstand a greater strain when arranged in one way than in another, has enabled the engineer to arrange his chief building materials, cast-iron and steel, in such a way that the members, say in the construction of a lattice girder, shall be disposed in it so that the cast-iron shall always be in compression and the steel in extension, and thus their respective advantages used in the best and most efficient manner. By this means the same strength can be obtained, and the weight much reduced. For example, the celebrated Britannia Tubular Bridge over the Menai Straits between the Welsh coast and the Island of Anglesea, and which was the crowning work of Robert Stephenson, could to-day, by the application of the above principles, be made a much lighter structure, and yet equally solid and safe.

The microscopical examination of the principal fibres used in the textile trades has conclusively shown that these fibres are marvellous mechanical structures in which the material composing them is arranged in an almost endless variety of methods, and that this structure ought to be taken into account when selection is being made of them for any particular fabric. So also it reveals a conclusive reason why the methods and machinery employed in transforming them must differ in each case so that the structural peculiarities shall be used in the best manner, and therefore the best value obtained in every case. This work is intended to deal with this department of technology, especially both in its mechanical and chemical aspects.

The wide range which such an inquiry must necessarily take will prevent the consideration of the specific methods of manufacture, except in as far as they are conditioned

by the nature of the raw material being used and the reciprocal action of the machines upon the raw material. In the same way the inquiry into the origin and development of the wool and other allied fibres will be guided by the endeavour to subserve the knowledge so obtained to the considerations of methods and processes, which may tend to improve the raw material so as to better fit the wool for the purposes of the manufacturer, such as the improvements in the breed of sheep, and the methods of scientific agriculture in relation to their feeding and maintenance in health and condition, all of which react upon the nature and structure of the wool.

Before pursuing these inquiries it is necessary to consider shortly the nature and structural peculiarities of the different classes of raw material which are used in textile manufacture, as these are often used in combination. To do this successfully necessitates a knowledge of their differences as well as their structural agreements, so as to enable the manufacturer to select those which are most suitable for combination along with wool, and treat the raw material when combined so as to bring out the best qualities of each.

This is specially necessary when the mixed fabric has to undergo any chemical treatment, because the chemical peculiarities and affinities of the different classes of raw material are essentially diverse.

CHAPTER II

CLASSIFICATION OF FIBRES

THE raw materials which are used in the manufacture of textile fabrics are derived from a great variety of sources, and our complicated civilisation now demands a continually widening range of new fibres, so as to satisfy those requirements.

Every source of supply from the animal, vegetable, and mineral kingdoms are now being drawn upon, and the resources of the chemist and mechanician are being called into operation to supplement even this abundant variety by the production of artificial fibres possessing new properties and advantages. This is necessitated by the fact that in the clothing of our bodies, the furniture of our houses, and the various articles for decoration and utility, which are now deemed indispensable in all civilised countries, there is an increasingly wide demand; while the quickening impulse of competition in business necessitates the employment of new forms and combinations as well as, if possible, the discovery of new materials which can be utilised in the manufacture of textile novelties.

Notwithstanding any of these new materials, by far the largest supply comes from sources with which manufacturers have been familiar from the remote past in the

countries from which they are respectively derived, and the facilities that are now given by means of improved transport have greatly widened the area which can be relied upon for supply. Cotton is now coming in increasing quantities from parts of the world such as Africa, Australia, and the Australasian Islands, and from all parts of the British Empire within the Cotton belt, which, if the supply continues, will probably render this country independent of the United States. And wool is now being derived from sources which a few years ago did not supply a fleece, and in increasing quantities from the Argentine and other South American States, where the vast well-watered plains form an ideal feeding-ground and the sheep flourishes amidst a congenial environment.

As a rule, therefore, the largest supply of textile materials are those which have been already in use, such as cotton, flax, hemp, jute, and China grass or ramie, all of which are of vegetable origin; wool, goat, camel, and other hair derived from almost all the hair-bearing animals; and cultivated and wild silk derived from the cocoon of various species of the Bombycidæ, which excels all other fibres in fineness, flexibility, and lustre, and may be regarded as the most valuable and beautiful of all textile fibres.

These various fibres differ very widely in their nature. They all possess very different mechanical and chemical structure, which necessitates entirely different treatment in each case, not only in the method of preparation and in the machinery used in the manufacturing process, but also in the chemical treatment necessary to obtain the best results in the dyeing and finishing processes.

There are many ways in which a systematic classification of these various raw materials might be attempted, founded

upon their mechanical structure, but perhaps the simplest is that based upon their source of origin, although their other differences, such as their chemical constitution, must be touched upon. Classified in this manner, the list will stand as follows in regard to the vegetable and animal fibres principally in use:—

I. Vegetable Fibres.

1. Cotton (*Gossypium*).
2. Flax (*Linum usitatissimum*).
3. Hemp, including Manilla (*Cannabis sativa*).
4. Jute (*Corchorus*).
5. Ramie or rhea fibre (*Bœhmeria tenacissima*).
6. China grass (*Bœhmeria nivea*).
7. Miscellaneous bast and other fibres.

II. Animal Fibres.

(*a*) *Appendages of the Skin.*

1. Wool (sheep, *Ovis aries*).
2. Mohair (goat, *Capridæ angora*).
3. Alpaca (*Auchenia paco*).
4. Vicugna (*Auchenia vicunna*).
5. Coarse wools (wild goats, etc.).
6. Coarse camel and other hair.

(*b*) *Secretions.*

1. Cultivated silk (*Bombyx mori*).
2. Wild silk (Tussah silk).

III. Artificial Fibres.

1. Artificial silk or lustra-cellulose.
2. Celluloid fibres.
3. Animalised cotton and other fibres.

It is not necessary to deal with any of the mineral fibres, such as asbestos, or with metallic or artificial fibres, as

their use with the above fibres, except in the case of artificial silk (lustra-cellulose), is very limited.

There is a great difference in mechanical structure between all vegetable and animal fibres, both in regard to their ultimate constituents, which are always cellular, and their chemical composition. The vegetable cell, which forms the mechanical basis of all vegetable fibres, is always much larger than the ultimate cells of the animal fibre, and it is nearly always more irregular in form and polygonal in shape rather than rounded, as is the case in most animal cells. The great distinction, however, is in the nature of the material of which they are composed. The basis of all mature vegetable cells is a substance called *Cellulose*, of which there are many varieties, so that the term must be taken to represent a group of closely allied bodies rather than a single substance. They are all, however, comparatively stable compounds, insoluble in all simple reagents, at ordinary temperatures, and are non-nitrogenous and belonging to the chemical group known as carbohydrates, all of which are formed by the union of carbon, hydrogen, and oxygen.

The empirical composition of pure cotton cellulose may be represented by the following relative components:—

Carbon	44·2 per cent.
Hydrogen	6·3
Oyygen	49·5
	100·0

This corresponds, when perfectly pure and free from ash, with the statistical formula $C_6H_{10}O_5$, though it is generally regarded, on account of its reaction, of a higher degree of complexity as multiples of this unit, and as being represented by the formula $x(C_6H_{10}O_5)$.

As distinguished from this the basis of all animal fibres is *Gelatine* or some albuminoid body allied to it, and from which it is probably derived by the elimination of the sulphur in the formative process. There is no trace of cellulose in the structure of any organs in the animal kingdom. While the albuminoid molecule contains some of the same substances in its composition as the cellulose molecules, but in different proportions, it also contains two others, nitrogen and sulphur, so that the structure of the ultimate molecule or unit of the animal cell is much more complicated, and it will be necessary to look more particularly at this when we deal with the chemistry of the wool fibre.

The albuminoids or proteids are, however, found in the unchanged contents of vegetable cells, and especially in the seeds. It is in fact from these vegetable proteids that those contained in animals are formed, since, unlike the plant, the animal is incapable of building up more complex substances from the simpler food materials except in a very limited agree. They are received in the food by the animal, and assimilated apparently almost unchanged. The living portion of the contents of the cell, from which the material of the cell walls is built up, both in the plant and animal, is a substance called *Protoplasm*, of which the composition has not yet been determined. The empirical formula for the typical albuminoid, calculated from the composition of egg-albumin, and from that of some other members of the allied group of proteids, comes out to something like :—

Carbon	50	to	55	per cent.
Hydrogen	6·7	,,	7·3	,,
Oxygen	21	,,	25	,,
Nitrogen	15	,,	18	,,
Sulphur	0·4	,,	1·7	,,

The formula for a typical albuminoid calculated from the mean of these figures may therefore be represented by the following $C_{131}H_{210}N_{35}O_{44}S$. This calculated formula, however, cannot be regarded as anything more than approximate, as a very slight difference in the analytical results would make a considerable difference in the formula, but it affords an idea of the great complexity of the proteids.

Concerning the atomic arrangement of these compounds very little is known. They are usually lævo-rotary optically. Physiologists generally distinguish between albuminoids and proteids. The two differ mainly in the fact that the proteids are easily coagulated by heat as in the case of egg-albumin, while the albuminoids are typified by Gelatine.[1]

Protoplasm must, it seems, be regarded not as a definite and stable compound but a mixture of various closely allied bodies possessing a high molecular weight, which in the living organism are undergoing constant rearrangement amidst the multiplex activities that are always manifest in the metabolic changes within the vegetable and animal cells.

When the change undergone in the growing animal cell is complete, and the formed material derived from the protoplasm has become organised in the texture of the animal structure which forms the substance of the animal fibres, this gelatine or its congeners forms the largest part of their substance, whether the fibre be derived from the secretion of a worm, such as silk, or the hair of a goat, or the wool fibre from a sheep.

Gelatine and its congeners have a higher specific gravity than cellulose, and hence when thoroughly wetted, so as

[1] Bloxam's *Chemistry*, p. 748; J. A. Churchill, London, 1903.

to exclude air which gives buoyancy to the fibre, animal substances sink in water while vegetable fibres float on the surface. As a general rule, also, since the ultimate vegetable cells are larger than the animal cells, there are a larger number of the animal cells in the same weight, and they are closer knit together, and are therefore stronger than vegetable fibres.

The cells in both cases, however, are too small to be observed with the naked eye, and hence, when it is necessary to examine the ultimate mechanical structure of either vegetable or animal fibres, it is necessary to use the microscope.

Microscopical Examination.—In making the researches embodied in this volume the same microscope was used which was employed by the author in the examination of the structure of the cotton fibre, and in the work on this subject, which forms part of the same series,[1] a full description of this instrument is given, and the reader must be referred to this for full details. Sufficient to say that the microscope was one of the best which it was possible to procure, and it was fitted with every accessory which could render any assistance in making the most thorough examination.

The range of amplification was also as great as was possible to be used with any advantage, and was accomplished by means of a complete battery of eye-pieces and objectives, both dry and immersion, and which, combined, gave a range of from the natural size up to 10,000 diameters.

The means of illumination also were of the most perfect kind, so that the object could be viewed under the most

[1] *The Structure of the Cotton Fibre*, by F. H. Bowman, Macmillan & Co., Ltd., London, 1908.

diverse conditions, and thus enable its structure to be fully determined both by reflected and transmitted light. It may be said, however, that, except when it was necessary to examine the genesis of the fibres, the whole of the details of the structure of the fibres, so far as this is necessary for technical applications, can be accomplished by any ordinary reliable microscope which has an amplification up to 1000 diameters. The measurements were taken with a specially constructed micrometer capable of the very greatest accuracy, and although in many cases these differences vary only by quantities which are represented by many thousand parts of a linear inch, they are nevertheless quite essential to be known if we are to obtain the best results from the material.

Method of Preparation.—In order to arrive at the nature of the mechanical structure of the various fibres and their organic texture in the various parts, it was necessary to prepare the specimens so that they could be examined under the most favourable circumstances. For external examination the fibres were simply cleansed, from any mechanically adhering impurities, by washing with water or weak alkali, or other solvents, so as to get a perfectly clean surface, and then mounted in the usual way on glass slides, either dry or with Canada balsam, with covering glasses so that each specimen could be referred to again if necessary. Slides were also prepared, showing horizontal, vertical, and other sections, and to bring out the minute structure of the various parts reagents were employed so as to differentiate the ultimate structure of the constituent cells. Selected specimens were also treated with staining materials, such as carmine, picro-carmine, hæmatoxylin, eosin, and various aniline dyes. In cutting the sections of the wool fibres, as indeed of all isolated fibres, it is an

absolutely impossible task, on account of the delicate nature of the structure, to cut a thin section unless the fibres are enclosed in some supporting material; and of many that are now in use the author was most successful with paraffin wax, as when consolidated it was neither too hard nor too elastic, which is the case with glue or any gelatine preparation. Under the most favourable circumstances it was found almost impossible to get any one section which clearly exhibited all the parts with equal distinctness, but a number were obtained which gave with sufficient distinctness the structure of every part, so that an accurate knowledge of the whole was attained and comparison made with the work of other observers.

In order to understand, for technical purposes, the difference between the structure of wool and other animal and vegetable fibres, it is necessary to look at the structure of several types of fibre, and the chief amongst those derived from the vegetable world is cotton.

Cotton is a unicellular seed hair derived from various species of the genus *Gossypium*, belonging to the natural order of Mallows or Malvaceæ, which is a subtropical plant, and flourishes in suitable localities in a belt which encircles the earth within about 45° north and 35° south of the equator. This comprises the largest portion of the earth's surface, but the growth for commercial purposes is at present confined largely to the south part of the United States of America, Brazil, Egypt, India, China, and to a smaller extent in Australia and the Australasian islands, although efforts are now being made with success to extend its cultivation in South Africa and other parts of the British Empire.

The primary function of the cotton fibre or lint in the economy of the plant is to act as a protective covering to

the seed, in its earlier stages, and afterwards as a parachute, so as to assist in the distribution of the seed over a wide area, and thus secure a suitable lodgment in which it may germinate under the best conditions.

In its early stages of development the young growing fibre is enclosed in a pod or capsule which contains a number of seeds, and they are thus protected from injury until when fully ripe the pod opens, and the fibres quickly reach maturity under the influence of the sun and air.

The organic structure of the fibre is of the simplest character. It consists of a single elongated cell which is attached to the surface of the seed, and until exposed to the sun and air is round in section and filled with active protoplasm. This, as the ripening proceeds, deposits successive layers of cellulose, which is a carbohydrate having the composition $x(C_6H_{10}O_5)$, on the inner wall of the primary pellicle or sheath which forms the outer layer and containing vessel of the fibre. The continuous nature of the seed hair, which is not like many vegetable fibres produced by the fusion of a number of separate cells, but by one continuous elongated growth of one primary cell, forms one of the reasons why the cotton fibres are of such value as textile raw material. It is flexible in every direction, and has no cell-divisions, which, although they might have been absorbed, would still have left a weak place at every junction, or formed a strengthening ring, which would, as in flax and other bast fibres, have conferred greater rigidity, and thus interfered with its perfect flexure.

When the pod opens the protoplasm immediately begins to change in composition, and forms the deposits on the inner cell-wall with various degrees of thickness of cellulose, which thicken and strengthen the fibre in proportion to the degree of deposit. Other products are formed at the

same time as the cellulose, and consist of various astringent, sweet, and oleaginous bodies, the former of which are probably the result of the formative process of cellulose, and the latter give a coating of wax and other preservative materials to the outer pellicle, which prevent the interpenetration of moisture and seal the cell-contents except to the permeation of air.

As the process of ripening proceeds the deposit of the cellulose gradually diminishes the original volume of the cellulose, and a central cavity or lumen appears in the centre of the fibre. This cavity is seldom entirely filled up by the formed deposits, and hence the cell-walls shrink unevenly, and the section of the fibre then presents an oval and not a circular form. As the drying does not occur evenly in all parts of the fibre, there is a certain amount of twist in various directions according as the lines of shrinkage occur, so that the general appearance is like a twisted collapsed tube or thin ribbon with thickened edges, and the twist not like a continuous torsion in one direction like a screw, but sometimes to the right and then to the left in each fibre.

This twist, which is a characteristic of all cotton, even in the wild varieties, is largely increased by cultivation, and the torsions are most numerous in the best qualities of cotton. This property of the fibre is of the utmost value for textile purposes, because, when the fibre is spun and twisted into a thread, these twists form a means of enabling the fibres to hold together by locking into each other, and thus resist being drawn out longitudinally, and the strength of the thread is therefore far greater than it otherwise would be.

Many fibres allied to cotton, such as thistle-down, which has a beautiful lustre, cotton silk, cotton-sedge, etc., possess

no twist, and as a consequence have no commercial value for textile purposes.

When fully ripe the cotton fibres are easily detached from the seed, and form a fine elastic and tenaceous raw material, with a more or less creamy white colour in American and Indian, and a brownish-yellow in Egyptian. When seen under the microscope by reflected light cotton presents the appearance of a number of more or less twisted fibres, closely resembling a series of convoluted ribbons or collapsed tubes with the edges thickened as if it was only the central part of the tube which had collapsed. The whole surface is covered over with irregular wrinkles or markings both longitudinal and transverse at all angles, as if the surface or outer pellicle was dried up like the folds and wrinkles of the skin on the back of an aged person's hand. The fibres differ in many respects, but are usually of three kinds.

1. Thin ribbon-like fibres without any thickness or structure, which are either immature or dead, exhibiting few indications of any twist.

2. More mature fibres, where the edges are somewhat thickened and the surfaces are wrinkled, and a considerable number of characteristic twists visible, and which are half ripe or arrested in development.

3. Fully mature, robust, and ripe fibres with full twist and well-thickened edges and distinct central cavity or lumen.

Fig. 1 gives a good illustration of some of these fibres seen under the microscope and magnified 250 diameters.

These fibres are seen with transmitted light, which reveals the internal structure of the fibre better than with reflected light. The dried-up cell-contents are seen as a pith-like deposit in the central cavity, and the thickness of

the cell-walls formed by the successive layers of cellulose deposited on the inner surface gauges the degree of ripeness of the fibre.

In transverse section the form of the cotton fibre is oval or round in the most matured fibres, but in the largest number it resembles the figure 8 with the central portion not quite closed, like the section of a double-headed steel

FIG. 1.—Cotton Fibres. × 220 diameters.

A. Glassy structureless fibre.
B. Thin, pellucid, unripe fibre.
C. Half-ripe fibre, with thin cell-wall.
D. and E. Fully mature and ripe fibre, with full twist and thick, well-defined cell-wall.

rail used on the main lines of railways, while the unripe or dead fibres are quite thin, like the section of a ribbon. Under high powers of the microscope the cell-walls, especially when treated with various reagents, show distinct signs of successive concentric layers or rings of different densities. This feature is clearly seen in Fig. 2, which shows a longitudinal section of a typical fully ripe fibre magnified 250 diameters.

In this section four distinct parts are clearly visible,

A the outer sheath or pellicle, B the secondary deposit of cellular layers on the inner surface of the pellicle, C the denser layer which forms the wall of the central lumen or cavity D, which is filled with the deposit resembling the pith in the stem of a goose quill, and which consists of the inspissated protoplasm and other cell-contents. This section may be compared with that of a typical hair

FIG. 2.—Section of Typical Cotton Fibre. × 250 diameters.

A. Outer sheath or pellicle.
B. Secondary deposit of cellulose.
C. Denser layer, sometimes spiral in character.
D. Tube or lumen, with pith-like deposit and sometimes containing endochrome.

given in Fig. 7, where the distinction will at once be clearly seen. Sometimes, and specially in wild cotton, the deposit of cellulose occurs in a spiral form, which is always distinctive of vegetable fibre and never occurs in those of any animal.

The length of the cotton fibre varies with the species from which it is grown, and the following may be taken as a fair representation of the length and variation in length of the typical cottons used in commerce :—

TABLE OF VARIATION IN LENGTHS OF VARIOUS COTTONS

Name of Cotton.	Maximum Length in Inches.	Minimum Length in Inches.	Mean Length in Inches.	Maximum Variation in Inches.
Sea Island . .	2·27	1·35	2·30	0·39
Egyptian . .	1·75	1·25	1·50	0·50
Brazilian . .	1·80	1·35	1·57	0·55
American (U.S.A.)	1·75	1·35	1·07	0·60
Indian or Surat .	1·00	0·60	0·80	0·40

The variation in diameter is different in the several species of cotton and also in the fibres from the same species, and this variation is more difficult to gauge than the length, because, as the fibres in the matured cotton are not circular in section, and differ materially in the amount of ripeness, which is measured by the amount of deposit within the walls of the fibre, it is only possible to measure the diameter in the direction of the greatest diameter of the oval section of the fibre.

The following table gives a general indication of the diameter and variation in diameter of the fibres in the various cottons whose lengths are given in the last table :—

TABLE OF VARIATION IN DIAMETER IN DIFFERENT COTTONS

Name of Cotton.	Maximum in Inches.	Minimum in Inches.	Mean in Inches.	Maximum Variation in Inches.
Sea Island . .	0·00082	0·00046	0·00064	0·00036
Egyptian . .	0·00072	0·00059	0·00065	0·00013
Brazilian . .	0·00096	0·00062	0·00079	0·00034
American (U.S.A.)	0·00097	0·00058	0·00077	0·00039
Indian or Surat .	0·001	0·00054	0·00078	0·00046

These figures are not easy to carry or figure in the mind, but the relation between the length and diameter of a single fibre of American cotton may be illustrated by the fact that if a single fibre was magnified or enlarged until it was one inch in diameter the length would be about 100 feet, and if the fibres in a single pound of cotton, which would number about 14,000,000, were placed end to end, the average length of the whole would extend 2200 miles.

Flax.—Next in importance to cotton amongst the vegetable fibres must be mentioned flax. This fibre is not a vegetable hair like cotton, or having its origin as a product derived from the seed and connected with its protection and dissemination, but is obtained from an integral part of the plant's structure, and forms a large part of the volume of the stem. It is indeed only a representative of a large series of fibres which can be obtained from the inner lining of the bark of nearly every species of dicotyledonous plants.

These fibres are called bast fibres and are of the utmost importance from a commercial and industrial point of view, because they include in addition to flax such valuable materials as hemp, jute, ramie, and many others. These all differ in structure and possess different and special properties, but flax fibre may be taken as a typical example, and from it linen is manufactured.

This fibre is derived from a plant known botanically as *Linum usitatissimum*, belonging to the natural order Linaceæ, for although there are many plants of the same family, this is the only one in general cultivation. The so-called New Zealand flax is not a bast but a fibre derived from the leaves of the *Phormium tenax.*

The fibrous layer from which flax is obtained is formed of a reticulated series of lanceolate cells, the ends of which

interlock or lap over each other, and thus form a continuous layer or sheet when the vascular bundle is disintegrated. This layer occurs on the outside inner layer, which is called the *phloem*, as distinguished from the *xilem*, which is the true wood fibre, forming the axis of the plant, and constituting the principal part of the stem. Each separate fibre is formed of a number of cells connected in series, end to end, with a communicating opening from cell to cell. The diameter of the cells is irregular, and at the junction of each there are joints or thickening of the cell-walls which form projections or swelling both inside and outside the cell, giving the appearance of dislocations of joints that stiffen and strengthen the fibre and form thick overlying fissures, connected by short discs or rings, which, when the fibres are associated together in threads, greatly strengthen them, by catching on to each other and so preventing them being drawn out or slipping in the same manner as the twists in cotton or the serrations in wool.

In section the fibres are never circular but always polygonal, from being pressed together during the growth of the stem, and their formation and development takes place in the same way as cotton, by the deposition of concentric layers of cellulose and cellulose-like bodies upon the inner wall of the cells in various forms of mechanical and organic arrangement. The walls are always solid and thick, and the structure does not permit of the like flexure in every direction, the same as cotton, without rupture and weakening of the fibres.

When viewed under the microscope the flax fibre exhibits the appearance of a hollow, cylindrical tube, which is open at both ends. The tube, however, is not continuous as in the case of cotton, which, as already seen, is a single

cell, but is separated by distinct joints or knots which appear at intervals irregularly distributed in the length of the fibre, at distances from two to eight times the diameter of the fibre. The diameter of the fibre varies in the different qualities of commercial flax from $\frac{1}{1000}$th to $\frac{1}{1800}$th of an inch.

Fig. 3 gives a good illustration of typical flax fibres, viewed with transmitted light and magnified 300 diameters, where the various features above described are clearly seen.

The tubular structure is well marked as well as the dividing septa or knots. These divisions mark the extremities of the cells, which during the growth of the plant form the channel within which the juices and sap circulated and connected cell with cell by a minute canal passing between the cells through the substance of the knot in the central axis, the thickness of the cell-wall being produced by secondary deposits upon the primary sheath.

When the fibrillæ are treated with a solution of iodine and sulphuric acid, the spiral character of the secondary deposits can be clearly seen, but there is no disposition, as in the case of the cotton fibre, to form a spiral tendency or twist in the fibres themselves, this tendency being strictly confined to the secondary deposits within the cell walls. When spun into yarn the adhesive power which the fibres possess does not depend upon the arrangement of the fibres into contiguous grooves, as in the case of cotton, but upon the mechanical twist which is put into them by the operation of spinning, and also to the knots, which catch upon each other, and the rough nature of the outer sheath of the fibre, which is more or less pitted in character, arising from the incrusting deposit of resinous matter which can never be entirely removed.

The resinous matter is of a yellowish-grey colour, and formed the cement which in the plant stem united the separate fibrillæ into vascular bundles.

The thickness and density of the tube-walls render the flax fibre stronger in proportion than that of cotton; but as the tenacity of the separate cells at their point of junction, besides intercellular locking, depends upon

FIG. 3.—Flax Fibres. × 300 diameters.

A. Fibre treated with nitric acid.
B. Fibre treated with nitric acid, and then sulphuric acid and iodine, to show spiral fibres.
C. Fibre with solid structure.
D. End of fibre with undeveloped cells.

chemical rather than mechanical union, it is more readily injured by the action of reagents.

Like cotton the chemical basis of flax is cellulose, $x(C_6H_{10}O_5)$, but it is never in the same pure condition as when derived from cotton, because on the commercial scale the incrusting matter can never be entirely removed, and this, unless special precautions are observed, always interferes with the impregnation of the fibre with dyeing solutions. It affords, however, a means of chemically

distinguishing between cotton and flax, when they are associated in a fabric, by the difference in the reaction with caustic alkalies. Equal parts by weight of caustic potash and water at a boiling temperature may be employed, and when the cotton and flax are immersed in it for about a minute, the excess of solution removed by pressing between blotting paper, the resinous matter always associated with the flax causes it to assume a dark yellow colour, while the purer cotton either remains white or turns a bright yellow. (*Dyeing and Calico Printing*, W. Crookes, p. 16.)

Kuhlmann in some of his researches found that when very concentrated solutions of caustic potash were used cotton remains grey, while flax assumes an orange yellow, which he thinks is due to the presence of pectic substances associated with the flax fibre. (*Dyeing and Calico Printing*, W. Crookes, p. 65.)

The strength of the fibre-wall in flax enables it to resist the action of sulphuric acid longer than cotton, and the more distinctly tubular form of the flax fibre, the collapsing of which is prevented by the strengthening rings, enables the fibre when immersed in oil to retain a quantity of it even when submitted to considerable pressure, so that when a mixed cotton and flax fibre is immersed in oil and examined under the microscope, with transmitted light, the flax fibre appears transparent while the cotton fibres remain comparatively opaque.

The distance between the joints and the length of the individual cells differ in different qualities of flax, and also the diameter of the cells, and the following table gives an average of the length and diameter in flax from various countries as given by Wiesner :—

TABLE OF LENGTH AND DIAMETER OF FLAX FIBRE.

Kind of Flax.	Mean Length of Flax Fibre in Millimetres.	Mean Diameter of Flax Fibre in Millimetres.
Egyptian . .	960 (38 in.)	·0255 (·00102 in.)
Westphalian .	750 (30 in.)	·0114 (·00045 in.)
Belgian . .	370 (15 in.)	·0105 (·00042 in.)
Austrian . .	410 (16 in.)	·0202 (·00081 in.)
Prussian . .	280 (12 in.)	·0119 (·00047 in.)
Irish . .	625 (25 in.)	·0105 (·00042 in.)

The flax plant is an annual, and rather delicate in growth. To obtain the fibre the plant is cut down, and after the leaves and seeds have been removed from the stem, the stalks are tied in bundles and subjected to a process called "retting," which consists in steeping the bundles in water, where they are allowed to remain until a process of fermentation occurs which decomposes the tissue enclosing the fibres and so enables them to be separated. When the retting process is completed, which takes about a fortnight, the stalks are passed through a mechanical process to remove the fibre from the decomposed tissues, and they are then obtained in a comparatively pure condition. The intercellular substance, which holds the fibres together, consists largely of calcium pectate, and the chemical change which accompanies the retting process results in rendering this body soluble and thus easily disengaged from the fibres by the solvent action of the water, and leaving the fibres free to be separated from each other. There are various processes for retting the fibre, and many attempts have been made to improve and accelerate the process by the addition of various chemicals, and also to supersede it by heating the bast with hot water under pressure, or boiling with solutions of various acids

or alkalies; but none have been found to answer the purpose better than retting, the action of which depends upon the presence and development of an anaerobic bacillus, which is the active agent in the fermentative process.

Flax is the strongest of the true commercial bast fibres, and its length, softness, and flexibility render it admirably fitted for textile purposes. It is extensively used not only in the manufacture of linen, but also of thread, net, and other reticulated articles.

Flax may be taken as typical of all the bast fibres such as hemp, jute, etc., and also for such vegetable fibres as ramie or China grass, which, although similar, are really derived from two separate plants of the same natural order, the former growing best in tropical and the latter in temperate climates. These fibres have a high surface lustre.

Amongst fibres derived from the animal kingdom, and exclusive of those produced by the higher vertebrates as an appendage of the skin, the most beautiful and widely known is silk.

Silk is the product of a species of caterpillar, which is the larval form of a moth, one of the family of the Bombycidæ. Though there are many varieties of silk-worm, some of which are wild and produce tussah silks, the mulberry silkworm (*Bombyx mori*) is the one which is best known and which is universally cultivated. The silk fibre in the economy of the worm is the thread which is secreted to form the outer covering of the case or cocoon which enswathes the chrysalis of the future moth during its pupa state.

The fluid to constitute the silk fibre is exuded through two ducts or openings, at the head of the worm, which

enter a common orifice, through which it passes into the air, where the fibres coagulate into a firm continuous filament. As the two separate streams of viscid secretion pass out at this orifice they are coated with another secretion, which differs in chemical composition, and which is exuded from two other glands, and this cements the fibres together into a double strand. When the time for the pupal state is concluded the young moth eats through the wall of the cocoon and emerges into the air, and in so doing destroys the continuity of the silk fibre. To obtain the fibre intact and of the full length the cocoon is heated by steam before the emergence of the moth, to a sufficient temperature to kill it, and then the cocoon is placed in hot water, which melts the cementing material and enables the two filaments, either singly or in combination, as may be required, to be unwound or wrapped on to a reel or bobbin, when it forms the spun silk of commerce. The fibres thus unwound from the cocoon are of great length, as many cocoons yield 1500 feet, and are distinguished for their high lustre, great elasticity, tensile strength, and perfect flexibility. The silk fibre is indeed the most perfect known to commerce, and has no equal in all those properties which are most desirable in a fibre for textile purposes. The silk fibre is capable also of being dyed any colour without injury to its strength or lustre.

Fig. 4 gives an illustration of the appearance of the silk fibre when seen under the microscope and magnified 260 diameters. The double nature of the fibre is distinctly shown, and on some parts of the fibre the whole of the cementing gum has not been entirely removed, as at A and B. The surface of the fibre when seen by reflected light is very bright and lustrous, and usually, unless artificially bleached, has a yellow or creamy-yellow

tinge, and in parts where the two fibres are not degummed the surface shows various striæ or markings, both transverse and longitudinal. The fibres, when together, are of oval section, with a longitudinal groove which marks the point of contact between the fibres, and when single the section is seldom round and generally an oval with irregular outline. When used for textile purposes the great length of the fibres enables them to hold or catch upon each other, where the twist is put in, as they afford sufficient holding surface to prevent being drawn out irregularly; but the plastic nature of the fibre also enables them to bind together, and their mutual indentation secures their adhesion.

Silk is the fibre of luxury, and although there are now rivals, as the result of the applications of the various solutions of celluiose to the production of what is known as artificial silk, they lack many of the best qualities of silk, and except where cheapness in price is necessary, cannot be employed except as substitutes.

The average breaking strain of raw silk is equivalent to 64,000 pounds per square inch, which is about equal to one-third of that of the best iron wire. When the silk is degummed there is a decrease in tensile strength of about 30 per cent, and the elasticity is less by about 45 per cent. These properties, as well as the diameter of the fibres, vary in different qualities of silk and also in the same fibre of the same quality of the silk, depending upon the position in the cocoon, the inner portion of the fibre being usually rather larger in diameter than the outer part of the fibre, and both the elasticity and tensile strength of the inner part of the fibre being the greatest. The following table showing these variations is given by Sir Thomas Wardle in the *Journal Soc. of Arts*, vol. xxxiii. p. 671 :—

TABLE OF DIAMETERS, ELASTICITY, AND TENSILE STRENGTH OF VARIOUS SILKS

Name of Silk.	Country.	Diameter of Fibre in Inches.		Elasticity per Foot in Inches.		Tensile Strength in Drams.		Size of Cocoon in Inches.
		Outer Fibres.	Inner Fibres.	Outer Fibres.	Inner Fibres.	Outer Fibres.	Inner Fibres.	
Bombyx mori . . .	China	0·00052	0·00071	1·3	1·9	1·6	2·6	1·1 × 0·5
,, ,, . . .	Italy	0·00053	0·00068	1·2	1·9	1·9	2·6	1·2 × 0·6
,, ,, . . .	Japan	0·00057	0·00069	1·2	1·4	2·0	3·1	1·1 × 0·6
Bombyx fortunatus .	Bengal	0·00045	0·00051	1·8	2·3	1·6	2·8	1·1 × 0·5
Bombyx texor . .	India	0·00042	0·00047	1·5	1·9	1·4	2·6	1·2 × 1·5
Anthercea Mylitta . .	,,	0·00061	0·00072	1·9	2·7	6·6	7·8	1·5 × 0·8
Attacus Ricini . .	,,	0·00085	0·00093	1·7	2·0	1·5	3·0	1·5 × 0·8
Attacus cynthia . .	,,	0·00083	0·00097	2·6	2·9	2·4	3·5	1·8 × 0·8
Anthercea Assama . .	,,	0·00128	0·0012[illegible]	2·4	2·8	2·8	4·8	1·8 × 1·0
Attacus Selene . .	,,	0·00100	0·00109	2·9	2·8	2·4	4·0	3·0 × 1·2
Attacus Atlas . . .	,,	0·00102	0·00111	1·9	2·8	2·1	4·1	3·5 × 0·8
Anthercea Yama-Mai .	Japan	0·00088	0·00096	2·0	4·0	6·8	7·5	1·5 × 0·8
Oricula trifenstrata .	India	....	0·00120	...	...	...	...	2·0 × 0·8
Anthercea Pernyi . .	China	0·00118	0·00138	2·0	2·7	3·2	5·8	1·6 × 0·8

The chemical composition of silk, like that of all animal fibres, is very complicated, and consists principally of two different substances, the one of which, *fibroin*, constitutes from one-half to two-thirds of the whole of the inner part of the fibre which consists of the substance of the two primary fibres. This is an albuminoid of great complexity, and the researches of Knecht and others show that it is an amido body having both acid and basic pro-

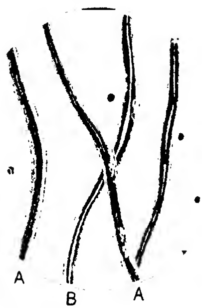


FIG. 4.—Silk Fibres. × 260 diameters.
A. Fibres showing longitudinal groove.
B. Fibre in which the groove deepens into complete separation of the two parts.

perties. Unlike keratin, the proteid of wool, the fibroin contains no sulphur, and is much more constant in its composition. It is insoluble in water.

Mulder gives the composition as follows:—

COMPOSITION OF FIBROIN

Carbon	48·80 per cent.
Hydrogen	6·23 ,,
Oxygen	25·00 ,,
Nitrogen	19·00 ,,

This corresponds to the empirical formula $C_{15}H_{23}N_5O_6$.

Richardson suggests the following constitutional formula, allowing x to represent the hydrocarbon residue:

$$x\begin{matrix}\diagup NH - CO \diagdown \\ \diagdown CO - NH \diagup\end{matrix}x$$

The other substance, which forms the cementing material which enswathes the two fibroin fibres and cements them together, is called *sericin*, and its composition is given by Richardson as:

COMPOSITION OF SERICIN

Carbon	48·80	per cent.
Hydrogen	6·23	„
Oxygen	25·97	„
Nitrogen	19·00	„

which corresponds to the formula $C_{15}H_{25}N_5O_8$, and unlike fibroin it is soluble in water, and can thus be removed by simply boiling it in water, when the "brin" or true silk which it covers is degummed and left in a condition ready for the manufacturer. The silk is also at the same time freed from colour, most of which is associated with the sericin and not the fibroin.

CHAPTER III

STRUCTURE OF THE SKIN

AMONGST animal fibres, next after silk, must be classed those which are derived from the higher vertebrates, and which include all forms of hair and wool; and here the nature of the work which is intended to form the subject of this volume is entered upon. As was the case in regard to the treatise on the cotton fibre, which occupies a previous volume of this series, it is not the intention of the author to deal directly with any manufacturing process, but rather to confine attention to the nature and properties of the raw material itself, and the conditions under which the variations in the structure occur, and their origin, with a view to point out how the various properties are modified and thus rendered better fitted for use under specific conditions.

The inquiry will necessitate a knowledge of the origin and development of the various fibres, and of the physiological conditions under which the variations occur.

Such an investigation demands a wider range of subject-matter than was necessary when the inquiry was confined to the fibres having their origin in the vegetable kingdom, inasmuch as the metabolic changes are greater and more complicated in animals than in plants, and the materials

which form the fibres have a more complicated chemical and mechanical structure than those which belong to the series of carbohydrates.

Amongst fur-, hair-, and wool-bearing animals the most useful and necessary fibres are supplied by one order in the animal kingdom, the Ruminantia, or animals which chew the cud, and which includes sheep, goats, camels, cows, etc., and their congeners. The fibres are an appendage of the skin, and form an outgrowth from it, and are not like vegetable fibres, such as cotton, merely attached to the surface, but form an integral part of its structure, and with which in its earlier stages, development, and maturity it maintains an organic union.

Hair, wool, and even the feathers of birds are very similar to each other in their essential nature, and are all produced in the same way by the production and determination of similar epidermic or skin cells at the bottom of a cuticular depression or follicle, which is flask-shaped and deeply embedded within the surface of the skin.

This follicle or flask is formed in the substance of the true skin, and is supplied with an abundance of blood by a special distribution of vessels within its walls. These vessels are continued as a fine network a short distance beyond the root, and thus feed the cells until they are fully developed.

In the case of some diseases of the hair, such as *Pica polonica*, they become enlarged, and allow the blood to penetrate into the substance of the hair, so that if the hair is cut or broken it bleeds.

If a hair is pulled out by the root, it will be found that there is always a bulbous enlargement at the bottom end, of which the exterior is tolerably firm; but the interior consists of a soft pulpy substance. The pulp is composed

of a mass of newly formed and uncondensed cells, and the continual production of these and their modification and conversion into the substance of the hair, as the hair is pushed upwards from the bottom to the orifice of the follicle at the surface of the skin, is the cause of the growth of the hair.

This method of generation and growth, however, supplies no explanation of the differences which are seen in the arrangement of the cells and their relation to each other, or their modification, which is manifested in the special forms which different fibres of fur, hair, or wool assume on different animals, although the appearance of the bulbous parts of each are very similar, and no examination has disclosed the reason for these differences.

All the different structural parts of the hair are only modifications of the organic structure of the skin, out of which it grows, and which have had a vertical rather than a horizontal determination given to them. The cause of this determination is unknown, but the mechanism of it is associated with the presence of nerve fibres, which, like the blood-vessels, penetrate the outer sheath of the hair within the follicle, at its lower part, and thus the hair is put in connection with the nervous system of the animal.

A series of small muscles are also always attached to the outer sheath of the follicle, which control its direction in the skin, and a sudden shock to the nerves will sometimes cause these to contract in such a manner that the direction of the follicle, with its contained hair, becomes vertical to the surface of the skin, and thus warrants the expression that the hair stands on end. This is well seen in the erection of the hair on the neck of a dog when excited and angry.

Although at first sight the structure of the skin, either of man or any of the lower vertebrates, appears to be a simple external layer covering the whole surface of the

softer portions of the body, it is really a very complicated structure.

The Skin of all animals consists of a series of strata or layers, one overlying the other and possessing different texture, which may be divided into two sharply defined groups, each of which consists of several more or less distinct layers.

These two principal divisions are respectively called (I.) the *epidermis*, which is the outermost and lies over (II.) the more deeply seated *dermis* or cutis vera. The epidermis when examined in the vertical section under the microscope, and when the parts are brought into prominence by the use of suitable staining materials, reveals six more or less distinct layers, which may be divided into two groups, of which three form the upper or scarf skin, and three the lower, called the rete mucosum or Malpighian layer, from its first observer Malpighi.

The dermis or cutis vera is formed of two layers, the upper called the papillary layer, and the lower the corium, which rests upon, and merges into, the subcutaneous tissues of the body.

This stratification, which must be examined in detail since it is within these layers that the follicles and hairs originate, may be tabulated as follows, commencing at the outside:—

I. Epidermis	1. The cuticle.	Scarf skin.
	2. Loose horny cells, stratum corneum.	
	3. Stratum lucidum.	
	4. Stratum granulosum.	Rete mucosum.
	5. Prickle cells—in several rows.	
	6. Columnar cells, one row.	
II. Dermis.	7. Papillary layer.	
	8. Corium.	

It has already been seen that the solid material of all plants is built up of small, variously shaped, sac-like bodies or cells, which enclose within their walls, during the growth of the plant, the protoplasm or juice by means of which the substance of the plant is formed by the metabolic changes which occur within the organism.

In the same way all animal substances are, in like manner, built up of cells which differ only from those found in plants in their size, shape, and chemical composition. The method of growth of these cells is identically the same in plants and animals, and in their earlier stages of development it is quite impossible, with the microscope alone, if the position in which they are found be neglected, to distinguish one from the other.

The protoplasm, which forms the ultimate germinating material in each, is undistinguishable by any means at our command either mechanically or chemically.

1. **The Epidermis.**—If a brush or rough substance, such as a piece of black cloth, is taken and rubbed upon the surface of the skin, especially in a dry place, like the back of the hand or the thigh, a quantity of dry light-coloured dust will be rubbed off and attach itself to the cloth. If this is examined under the microscope, it will be seen that this dust consists of a series of detached flattened scales. These are the epidermal cells, which form the outer surface of the skin, and which, having performed their function in the economy of the body, are being thrown off and replaced by others that are being renewed continuously from beneath.

These epithelial scales are dry, hard, and horny, and sometimes constitute the larger portion of the epidermis, and differ in form from the outer to the inner layers. In the outer layer or cuticle the cells are always structureless

and flat, exhibiting no cell-contents, and dry and hard, with a chemical composition closely resembling horn. These are clearly seen at A in Fig. 5, which represents a vertical section of the skin.

Beneath, in the second layer, seen at B, the cells are less flattened and more closely arranged, with irregular double

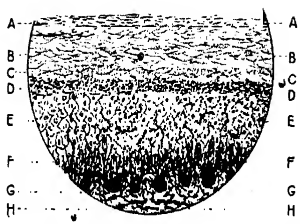


Fig. 5.—Vertical Section of the Skin. × 175 diameters.

Epidermis:
- A. Scarf skin.
- B. Horny cells, stratum corneum. } Scarf skin.
- C. Stratum lucidum.
- D. Stratum granulosum.
- E. Prickle cells—nucleated. } Rete mucosum.
- F. Columnar cells.

Cutis vera:
- G. Papillary layer.
- H. Corium.

convex surfaces, and packed together so as to form a more or less elastic bed upon which the upper stratum rests, the cells becoming more flattened and dried up as they approach the outer cuticle into which they merge. The third layer, C, or stratum lucidum, consists of a series of similar shaped cells, which exhibit more or less granulation in their structure, and in which the cell-contents are not entirely inspissated, and they rest more or less conformably in the horizontal

direction upon the stratum granulosum, D, which forms the upper layer of the rete mucosum, from which the layer is constantly being renewed by the passing upward of fresh cells from its surface, many of these cells showing traces of a nucleus. The fifth layer, E, is usually of considerable thickness, and the form of the prickle cells, as they are called, in section, is that of irregular polygons with a distinct nucleus and granulations, but the shape gradually changing in the deeper rows to an elongated form, arranged gradually into a vertical position, and ultimately passing into the single row of vertical columnar cells, F, which form the base of the rete mucosum, and which fills in the substance between the papillæ of the upper layer of the dermis. These cells are rich in protoplasm, and indeed in the stratum lucidum as well as the stratum granulosum the cells are filled with small drops of a material which stains deeply with carmine.[1]

The growth of the epidermis takes place entirely by the multiplication of the cells in the deeper layers, and as these grow, and pass upwards, they undergo mechanical and chemical changes, differing with the layers into which they pass, until finally their protoplasm is transformed into the horny material of the superficial strata, and they are thrown off as scarf skin. The greatest change seems to occur within, and just above the fourth layer, D, the stratum granulosum, where the cell granules are composed of a substance called eleidin, closely allied in composition to keratin, which is the basis of horns, hoofs, and nails.

2. **The dermis or cutis vera** is formed of dense modified connective tissue called the corium, the upper surface of which forms the papillary layer, G. These projections of papillæ pass upwards into the rete mucosum,

[1] *Essentials of Histology*, Schäfer, London, 1907, p. 228.

which is moulded over them and fills up the spaces between. The upper layer of the corium is rich in a network of blood-vessels, looped capillary prolongations, many of which pass into the papillæ, and others rise upward and supply with nutriment the various appendages embedded in the skin, such as sweat glands, hair follicles, with their coating, muscles, and glands.

These papillæ also frequently contain tactile corpuscles, with double nerve fibres entering them, and upon these the sense of feeling depends. On the general surface of the body the papillæ are short and minute, but they increase in size and differ in arrangement in various special situations, as in the human body on the surfaces of the hands, feet, and other parts where great sensibility is requisite. This layer is chiefly composed of areolo-fibrous tissue, elastic tissue, and smooth muscular fibre, and is highly vascular and sensitive.

The corium or deep-seated stratum, H, is lowest of all, and is connected with the denser papillary layer above. It consists of areolo-fibrous tissue, which is collected into cellular bundles, called fasciculi, which are small and closely interwoven in the superficial strata, and large and coarse in the lower strata, forming an areolar network with large openings, which serve as channels, through which the branches of the larger blood-vessels, lymphatics, and nerves pass outwards to the surface of the skin. Beneath the corium is the adipose layer, which always contains a number of clusters of fat globules, which are irregularly dispersed throughout the areolo-fibrous tissue as seen at I and J in the lower part of Fig. 6.

Section of Skin.—Fig. 6 gives an illustration of a vertical section of the skin magnified 250 diameters, in which the various layers as detailed above are distinctly

seen. In the deepest layer of the rete mucosum, B, which lies upon the papillary layer, there are fine intercellular clefts, which separate the columnar cells from each other, and which serve for the passage of lymph; and it is in these cells also that the coloured pigment granules are developed

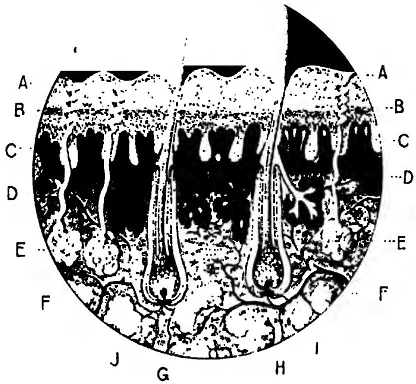


FIG. 6.—Diagrammatic Section of the Skin. × 125 diameters.

A. Scarf skin or cuticle. C. Papillary layer. E. Sudoriparous glands.
B. Rete mucosum. D. Corium. F. Adipose or fat cells.
G and H. Hair follicles. I and J. Sebaceous or oil glands.

which give the colour to the skin of the negro and other dark-skinned races.

From the upper layer of the cutis vera, also in addition to the blood-vessels, there extends upwards a fine plexus of nerve fibrillæ, which are distributed like the blood-vessels to the various appendages which are embedded in the skin, and in Fig. 5 some of these vessels and nerves are seen distributed amongst the cells, as high as the stratum

lucidum, in which layer all the nuclei in the cells disappear. This section represents a portion of the skin in which no appendages are enclosed, but this must be taken as diagrammatic, because no area of this size could be found which did not contain traces of one or more of them, and they are essential to the economy of the animal.

Appendages of the Skin.—The skin is everywhere penetrated from beneath to the surface by a series of channels or openings, called sudoriparous ducts, seen at E in Fig. 6, through which the perspiration or moisture, from the fatty or adipose layer, which lies beneath the cutis vera, escapes into the air.

The secreting glands which throw off this moisture are embedded in the substance of the skin and subcutaneous tissue, and present every degree of complexity from the simplest follicle to the compound lobulated gland.

In some portions of the body the excretory ducts open on the surface of the skin, with a sinuous outlet through the layers of the skin, while in others they terminate in what is of most interest to the readers of this book, viz. the follicles of the hair or wool, which, like themselves, have their origin within the surface of the skin, and pass upwards through it to the surface of the body, and which are seen at I and J on each side of the hair follicle.

Hairs and wool are therefore living appendages of the skin produced by the involution and subsequent evolution of the epidermis; the involution constituting the follicle or sac in which the hair is enclosed, and the evolution the shaft of the hair. These follicles are seen at G and H.

Before looking at the method of generation of the hair, and its relation to the skin, it is necessary to look at this section of the epidermis and cutis vera with the various appendages *in situ* from which the nature of these

appendages and their various parts can be better understood than by any written description.

It is a diagrammatic representation of a vertical section of the skin as it would be seen if magnified 125 diameters. In this case the human skin has been selected, as the author has in his possession a series of stained slides which exhibit all the various parts, but the skin of the higher vertebrates is identical in general structure, and only differs in minute details on account of its being more delicate and the hairs usually arranged singly and not in tufts.

The cuticle or scarf skin is seen at A, with a series of dead, loose cells upon the surface. Between these surface cells and the rete mucosum, B, which lies upon the columnar cells, the stratum corneum, and the two layers, stratum lucidum and stratum granulosum, will be seen. The papillary layer at C shows the penetration of the papillæ into the rete mucosum, and in some of them on the right hand tactile nerves are seen enclosed within them, with fine network of nerve fibrillæ at their termination.

Below the papillary layer, at D, is the corium, which becomes less dense as it proceeds inwards, and finally merges into loosely knit, areolo-fibrous tissue, arranged in fibrous bundles, which enclose a network of ramified blood-vessels and nerves so distributed as to form a vascular and nervous connection with the numerous appendages of the skin, which are enclosed within it, and thus in living union with the body of the animal.

These appendages may be considered as of three kinds:

1. *Sweat or sudoriparous glands*, which are seen with their winding spiral ducts opening out on to the surface of the skin after traversing its various strata. They act as drainage tubes to remove accumulation of water and lymph associated with the tissues. They are very abundant over

the whole surface of the body, and are specially abundant in the palm of the hand and the soles of the feet. They are generated, like all appendages of the skin, by downgrowths from the rete mucosum into the corium, in the deeper part of which the gland assumes the form of a coiled tube, slightly curved in the duct, which passes upward until it reaches the stratum granulosum, when it takes a corkscrew form to the surface. The secreting gland is a convoluted tube, usually larger than the effluent duct, and the walls of the tube are formed of a double layer of epithelium cells, and the duct has a similar wall structure which, however, ends at the surface of the rete mucosum and is continued upward by the convoluted channel excavated between the cells of the stratum corneum and scarf skin. The total length of these coiled tubes is very great, and it has been calculated that their aggregate length over the whole surface of the body totals upwards of forty miles.

2. *Sebaceous or oil glands* seen at I and J differ from sweat glands both in structure and function. They are small, saccular glands, not unlike in appearance to a small bunch of grapes, consisting as they do of a series of small secreting bulbs clustered round a branched duct, which is clearly seen by the section of a gland on the right hand in Fig. 6. The duct in the case of these glands never opens direct on to the surface of the skin, but into the walls of the hair follicles immediately below the papillary layer. There are usually more than one of these glands associated with each hair follicle. Both the saccules and the duct in these glands are lined with epithelium on the basement membrane, and probably, owing to the continual disintegration of these cells, the saccules become charged with sebaceous oily matter, which is discharged into the

hair follicle, and forms the lubricant which prevents friction in the outward passage of the hair to the surface. The hair thus carries the oil along with it forming the nutriment which supports and feeds its growth.

These glands in the sheep secrete the *suint*, which is so abundant, in the Merino sheep, as to form a considerable portion of the weight of the fleece, and preserves the wool from matting or felting by enswathing the fibres and preventing the surface scales from interlocking. These glands are not developed from downgrowths of the rete mucosum but by a lateral outgrowth of the sheath wall of the hair follicle.

3. *Hair Follicles or Sacs.*—These are pits or cavities formed in the skin by a downgrowth of the mucous membrane, and, like the skin itself, it is composed of two parts, one epithelial and the other connective tissue, which correspond, layer with layer, with the structure of the skin only in an inverted order, since the epidermic part of the follicle invests the hair-root, and hence is known as the root-sheath, while the external layer of the follicle represents the rete mucosum, but without the stratum granulosum.

The hairs, or wool fibres themselves, are formed or generated within the follicle in identically the same manner as the formation of the epidermis of the skin from the surface of the papillary layer. Plastic lymph is, in the first instance, exuded by the capillary plexus of vessels at the root of the follicle, and this material undergoes conversion, first into granules and then into nucleated cells, which, as the process of growth and extrusion proceeds, are elongated into fibres which form the cortical portion of the hair, while in those hairs where there is a medulla the cells in the central axis do not elongate but

remain of rounded or oval form. The cells which occupy an outward position, and which are destined to form the surface of the hair, go through a different process. They become converted into flat scales and entirely lose their cellular and nucleated form, and, as they are successively formed, each fresh one overlaps that immediately preceding it, which gives rise to the prominent and wavy lines that are always seen round the circumference and forming the outer cuticle of the hair.

Hairs are generally not quite round, but more or less flattened in form, and when the extremity of a transverse section is examined it is usually found to possess an elliptical or reniform outline. This examination also demonstrates that the centre of the hair is porous and loose in texture, while its periphery is dense. Just as we find in a section of a plant stem that the central cells are usually large and distinct, while those which form the outer layers are more closely packed together, and at the extreme margin increase further in density, and change the character of the cells so as to form a bark or skin, so in the hair we have a similar phenomenon, which enables us to distinguish its cross section into a central or medullary part, a cortical or intermediate part, and a cuticle or skin forming the outer portion. If we examine a longitudinal section of the hair we find the same divisions distinctly marked,—the dense outer sheath of flattened scales, with an inner lining of closely packed fibrous cells, and frequently a well-marked central vascular bundle of larger cells. These larger cells are, however, frequently wanting in many hairs. The extremity of the hair is usually pointed, but in some instances it is divided into several distinct filaments. The lower extremity of the hair is larger than the shaft, and forms a conical bulb or bundle of

cells, which has a circular section, and constitutes the root or growing portion of the hair. Its larger bulk is due to the larger size of the newly formed cells, which have just been thrown off from the layers in which they are embedded. These cells shrink in volume as they are pushed upward from their various growing points, and as they become more consolidated they form the shaft of the hair with its various parts. The hair makes its appearance on the skin of the animal before it possesses an independent existence.

Structure of Hair.—In order to thoroughly understand the structure of the wool fibre, which, as we have already seen, is a peculiar modification of the hair, and as we know more about the anatomy and mode of growth of a human hair than any other, we shall take this as a typical example. There are several different kinds of hair growing upon different parts of the body. The long fine hair of the head, which, in the case of the female, often reaches a very great length, 2 and even 3 feet or more, with a diameter of about $\frac{1}{300}$th of an inch, differing, however, very widely on different persons; also in adults a growth of hair under the arm-pits and at the junction of the legs, and in males not unfrequently on the breast; also a short stiff-pointed hair, from $\frac{1}{4}$ to $\frac{1}{2}$ inch long, as on the eyelashes; and a fine downy hair about $\frac{1}{12}$ to $\frac{1}{8}$th inch in length, which grows more or less upon the whole surface of the body, and can be seen very distinctly if we look along the back of the hand with the light shining upon it. All these various hairs have a great similarity in structure, differing indeed only in minute details, and possessing a common method of development. If we take a hair from the head, and cut it into section in the direction of its length, in the same way that a plank is cut out of the trunk of a

tree, we have a very beautiful appearance presented, in which we can, if we magnify it, say about 125 diameters, see distinct evidence of three different structural parts: (1) a central medulla; (2) a cortical substance, upon which the firmness, elasticity, and colour of the hair depends; and (3) on the outside a thin outer sheath or cuticle with serrated edge.

FIG. 7.—Longitudinal Section of Human Hair. × 125 diameters.

A. Central medulla with round nucleated cells.
B. Cortical substance with fibrillæ and lanceolated nucleii.
C. Cuticle with laminated plates and serrated edge.

Fig. 7 gives a representation of such a longitudinal section after the hair has been treated with an alkali so as to remove the natural fat and render the structure more distinct. A represents the central medulla, with its rounded and nucleated cells; B the cortical portion, with its elongated and striated cells, with fibrillation and linear nuclei, containing endochrome, upon which the colour of the hair depends; and C the outer sheath or cuticle, with its laminated cells and serrated edge.

Fig. 8 gives a representation of a transverse section of the same hair, magnified 350 diameters, and where we can see the various parts mentioned above with even greater distinctness than in the longitudinal section. Here it will be seen that the cells in the cortical portion of the hair have lost their round or oval form and are, by the pressure of the enswathing cuticle, forced to assume irregular polygonal

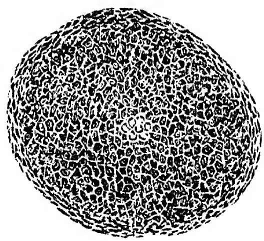


FIG. 8.—Transverse Section of Human Hair. × 350 diameters. Showing central medulla with round nucleated cells. Cortical substance with angular cells, and cuticle with elongated cells and laminated plates.

forms so that they present a close dense texture, but without losing their flexibility. If we treat the hair with strong sulphuric or some other acid at a gentle heat, we can break up the various parts of the hair into the constituent cells, and then only do we come to understand how complicated a substance a hair really is.

To accomplish this the method employed was the same as used by Nathusius and Bohn in their researches.

The fibre was placed upon a glass slide, and a covering-glass placed upon it and cemented to the slide by means of a drop of water, which holds the slide in its place. A drop of sulphuric acid was placed on the slide close to the edge of the covering glass, and was immediately diffused under the cover by capillary attraction. The action of the acid causes the fibre to expand and swell, and the surface scales to become distinctly visible and to stand out from the cortical substance. If the slide is gently warmed, these scales begin to curl outwards, and finally roll up and detach from the fibre and float away. These cells are very thin, and exhibit no signs of structure or any trace of a nucleus. The method of attachment to the cortical substance is not clear, and the author could not detect any trace of a dividing membrane. As the disintegration of the fibre proceeds, under the action of the heated acid, longitudinal striations appear in the cortical substance, and long, swollen, spindle-shaped masses separate which can be teased out into distinct cells until the whole cortex is broken up and shown to be composed entirely of these cells.

By counting a small portion of the cross section of a hair, in the cortical part alone it was found that the number of cells were not much less than 1500 in number in that cross section; and if we take them at an average length of $\frac{1}{400}$th of an inch, we arrive at the conclusion that there must be 600,000 of these cells in every inch of the length of the hair. This hair was taken off the head of a lady, but the author found in several coarse hairs a very similar average, the larger size of the hairs being made up by an increased diameter in the individual cells rather than in a greater number; it was also found that the number and size of the cells differ considerably in different individuals. Two other hair sections gave 900 and 1100 cells respectively.

Fig. 9 shows some of these constituent cells when they have been treated with various reagents so as to separate them and bring out the various points in their structure.

A represents a number of cells, such as constitute the medulla or central portion of the hair. They are more or less angular and also rounder, and vary in diameter from $\frac{1}{100}$th to $\frac{1}{2000}$th of an inch, and are about the same

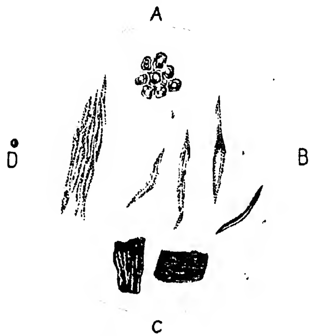


FIG. 9.—Cells constituting Hair. × 300 diameters.

A. Cells from medulla with nuclei and fat globules.
B. Cells from cortical substance with elongated nuclei and pigment cells.
C. Structureless horny scales from the cuticle.

length. They often exhibit a distinct nucleus and sometimes one or more little rounded globules of fat or some other substance; and when they become consolidated after being pushed forward from the bulb by the growth of cells behind them, they also contain air, which can easily be seen by macerating the hair in oil of turpentine, when the air is displaced by the liquid and escapes in minute bubbles. In many hairs these larger medullar cells are much diminished in size, and with a very faint

nucleus, and in some entirely wanting. In wool, by careful attention to culture and purity of breed in the sheep, these cells entirely disappear, and this often forms a ready means of distinguishing wool from hair, which usually contains a medulla in some part of its length. B represents a series of cells from the cortical part of the hair. Here they are aggregated in fibrous bundles, and also separated from each other. These cells present uneven surfaces, and a more or less uneven outline, their true form being spindle-shaped; but they are mostly flattened and angular, or curved from mutual pressure, resulting from their aggregation into the shaft of the hair. These cells vary in length from about $\frac{1}{500}$th to $\frac{1}{300}$th of an inch, and in diameter from $\frac{1}{6000}$th to $\frac{1}{2000}$th of an inch. When separated from each other by the action of alkalies, they swell up and become larger than when in the bundles in which they are associated in the substance of the hair, as if they were consolidated under pressure, and they also increase apparently in length as well as diameter, as if the whole enveloping membrane of the cell was distended in every direction by the swelling of its contents. They mostly contain elongated dark-looking nuclei, and in coloured hairs the small pigment granules to which the colour of the hair is due. These pigment granules are exceedingly minute, not more than $\frac{1}{50,000}$th of an inch in diameter, and are arranged in the hair in linear groups, their colour and number varying with that of the hair. At C we have a number of isolated epithelial scales from the surface of the hair, which are really flattened, inspissated cells, similar in character to those which form the outer cuticle of the epidermis of the skin, and which have a common origin.

To these scales we must call particular attention, because it is upon a variation in their character,

and the method in which they are connected with the cortical substance beneath, that the great difference between wool and hair consists, as well as the peculiarity which enables wool to mat or felt together. To enable this to be understood more distinctly we must look at Fig. 10, which represents a hair viewed by reflected light, so that we can see the nature of the surface or cuticular coat. In this diagram the hair has been freed from

FIG. 10.—Human Hair. × 120 diameters.
Surface of hair treated with caustic soda, so as to show epidermal scales.

all fatty and other sebaceous matter by being treated with a solution of weak caustic soda so as to enable the cortical scales to be detached at their free edges from the shaft of the hair without disintegration. Here we see at once the cause of the serrated edge when the hair was viewed in longitudinal section. The whole surface of the hair, at any rate above the termination of the inner root-sheath, is coated externally by a firmly adherent thin membranous layer, consisting of flat, imbricated, epithelial scales. These scales have all their

free margins directed towards the unattached end of the hair, and lie overlaping each other like the plates on the scaly back of a fish, or the tiles on a housetop. In the natural state of the hair, when it has not been treated by appropriate reagents, these scales lie so flat upon the shaft of the hair that it is almost impossible to see them, and their existence is only revealed by the presence of irregular, transverse, and anastomosing lines which cross the surface. If, however, the hair is treated with any reagent which disintegrates its component parts, the free margins of these scales are raised up, so that they at first stand off from the hair like the scales on a fir cone, and finally become detached from it altogether, so that they can be separately examined. The number of them on the surface of the hair varies considerably in different individuals, but an average of ten different hairs from several persons gave 3200 as the number of free margins in 1 inch. The length of the scales varied from $\frac{1}{600}$th to $\frac{1}{700}$th of an inch, and about $\frac{1}{1800}$th of an inch in diameter. The whole cuticle of the hair was formed of from three to five layers of these cells, and they are so closely cemented together, that when seen in section the cuticle presents the appearance of a transparent membrane with a serrated edge. When viewed in relation to wool, these scales are of great importance, because, as we shall afterwards see, upon them depends the distinction to a large extent between many classes of wool. They also vary in their nature and arrangement on the hairs of different animals, and also on hairs from different parts of the body of the same animal, so that it is often possible to distinguish by microscopical examination from what animal the hair has been derived and from what part of the body. It is not necessary to point out how very important this

is when it is necessary to determine whether yarns are composed of one class of fibre, or a mixture, and also what the character of the mixture is. The cause of these variations also is of the utmost importance, because a knowledge of the underlying causes enables us to modify them so as to produce a variation in effect which is often of the greatest value. To know this we must look at the method in which the hair grows, both upon the fœtal skin and when the creature has obtained a separate existence; because in the first case it is dependent upon the selection of sire and dam, and in the last upon the peculiar climatic and other conditions by which it is surrounded, as well as to a certain extent upon the food which is eaten.

CHAPTER IV

ORIGIN AND DEVELOPMENT OF THE HAIR

It has already been seen that the hairs are enclosed at the growing end within a follicle or pouch, which is an involution of the epidermis. These follicles are about $\frac{1}{10}$th to $\frac{1}{4}$ inch deep in man, depending upon the position on the body in which they are found. The follicle entirely encloses the hair and extends in the shorter hairs down into the upper layers of the cutis vera, but in the longer and stronger hairs into its deepest portion, and even in some cases into the subcutaneous cellular tissue.

This will be readily seen by looking at Fig. 11, where we have a transverse section of a hair and the enclosing follicle magnified 150 diameters, in which the sac penetrates down below the cutis vera into the deeper adipose layer which lies beneath it.

The walls of the follicle being a simple involution of the skin, they exhibit a similar structure, with corresponding layers or envelopes.

Structure of Hair Follicle.—Three separate parts are easily distinguishable in the wall of the follicle.

1. An external, transparent layer, which forms the inner wall corresponding with the epidermis of the skin of which it is an involution.

2. A much thicker, very fibrous and vascular portion, which forms the bulk of the follicle proper, and which corresponds to the rete mucosum, of the skin, and which in the lower part of the follicle comes in direct contact

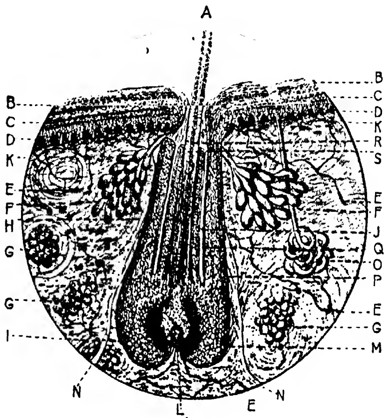


FIG. 11. Vertical Section of Human Hair Follicle. × 150 diameters.

A. Shaft of hair.
B. Epidermis.
C. Rete mucosum.
D. Papillary layer.
E. Blood-vessels.
F. Sebaceous or oil gland.
G. Adipose or fat globules.
H. Huxley's layer.
I. Basement membrane.
J. Henle's layer.
K. Cutis vera.
L. Papilla.
M. Erector pili muscle.
N. Nerve.
O. Sweat gland.
P. Outer root-sheath.
Q. Inner root-sheath.
R. Medulla of hair.
S. Fibrous cortical substance.

with the cells of the growing hair and the papilla from which it springs, and which it completely encloses.

3. A transparent sheath, called the basement membrane, of which the papilla is an involution, and which forms the external sheath or covering of the follicle It is a firm

elastic yellowish membrane, and terminates at the point where the sebaceous ducts open into the follicle.

As seen in section, the follicle presents the appearance of a most complicated structure, the various parts of which and their relation to each other it is almost beyond the power of words to describe, but which are all clearly seen in longitudinal section in Fig. 11, where all the various parts are detailed and their positions and names indicated by the letters and descriptive table beneath the diagram, and which was sketched from a section of the skin by the author. Generally it will be noticed that the follicle consists of three parts, as described above, and that immediately round the growing hair, which forms the central axis, there is an inner enclosing wall, separated from the involution of the skin by a small annular space, and then an evolution of this wall forming an inner enclosing tube in which the hair takes form from the conditioning of the cells which enter this tube from beneath. The hair itself is not in direct contact with the inner wall of this tube which is lined by Huxley's layer and is in closest contact with the hair shaft just at the point where it emerges from this tube. Henle's layer forms the outer sheath wall of this tube.

A cross section of the follicle just above the point where this inner tube is completely differentiated from the outer tube is seen in Fig. 12, in which the various layers are even more distinctly seen than in the longitudinal section, and can easily be recognised by reference to the lettering underneath Fig. 11.

The structure of this inner tube, which seems to act the part of a mould in the formation of the hair by receiving at its lower end the plastic active cells, which are continually being thrown off from the papilla and pressed

upward by those behind, is highly complicated, and its substance is connected externally at the lower end with the outer root-sheath and internally with the outer layer of the cuticle of the growing hair.

At first sight it appears as if perfectly homogeneous, but on closer examination it is found to be distinctly cellular.

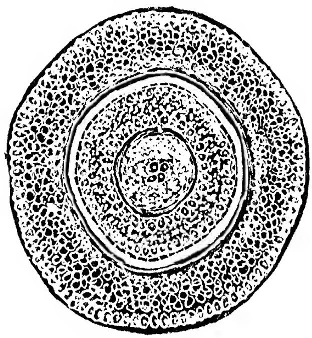


FIG. 12.—Cross Section of Human Hair Follicle. × 350 diameters.

Showing the outer tube-sac which is an involution of the epidermis and the inner tube, separated by an annular space, which is an evolution of the outer tube, and encloses the growing hair with its central medulla and outer enclosing cortical layer and cuticle.

It consists of two or three layers of polygonal, longish, transparent cells, with their long axis parallel to that of the hair. The outermost layer, called Henle's layer, consists of long flattened non-nucleated cells, from $\frac{1}{700}$th to $\frac{1}{500}$th of an inch in length, with fissures between them, thus forming a fenestrated or perforated layer. The innermost layer, called Huxley's, consists of one or two

layers of shorter or broader polygonal cells, from $\frac{1}{1200}$th to $\frac{1}{600}$th of an inch in length. Their nuclei, which exist only in the lower part of the coat, are often broader at the end than in the middle, and are sometimes curved and pointed. At the base of the hair follicle the inner root-sheath consists of a single layer only of beautiful polygonal nucleated cells, which, becoming soft, delicate, and rounded, gradually pass into the outer layers of the round cells of the bulk of the hair.[1]

The shaft of the hair comes in close contact with the enclosing walls of the inner root-sheath just below the point where the sebaceous ducts enter, and is also less consolidated higher up, the outer cuticular layer of the shaft being in close contact with the outer layer of the follicle itself, and the two cannot be easily distinguished except by the use of an alkali, as a reagent, when the shaft of the hair shrinks in upon itself and assumes an undulated form by the involution of its outer coating. Within the root-sheath, below the point of stricture, the cells of which the cortical part of the hair are built up are more rounded and of larger diameter than when the hair passes out of the follicle. They are, however, less in length, and it seems as if, as the process of growth proceeds, and the cells are carried outwards farther and farther from their point of origin, the consolidation which takes place elongates the cells at the expense of their diameter, and renders the hair shaft more dense and fibrous. The cuticle of the hair also undergoes a similar change. At the root of the hair, in the bulb, just where the epidermal cells are thrown off from the growing points, they are round and nucleated, but this rapidly disappears, and they assume the form of the flattened imbricated scales which

[1] *Micrographic Dictionary*, p. 334.

afterwards cover the surface of the hair. In the lower parts, however, they stand more outwards from the surface of the hair, and are thus more distinctly seen without the use of a reagent than when the hair has passed out beyond the surface of the skin. The shaft of the hair itself, when it passes out beyond the follicle, is, as a rule, straight, and to a certain extent stiff, but it possesses a very remarkable degree of tenacity when subjected to strain in the direction of its length, as well as power to undergo flexure without a rupture of the cells of which it is composed. Its cellular structure also enables it to retain its circular form under great pressure. It is also very elastic, and when subjected to strain draws out like an elastic band for a considerable length before it breaks. It should be observed that the follicles do not stand perpendicularly in the skin, otherwise the hair on leaving the surface would always stand erect. The position of the follicles is oblique, and hence the hairs lie smoothly, especially if they are allowed to take their natural sweep round the crown, which is their centre of radiation. Indeed, the hair on every part of the body, both in man and the lower animals, is arranged in various geometrical curves or currents, so as most suitably to conform to the contour of the body. This is well seen in the arrangement of the hair on the body of a horse. At the sides of the hair follicles, and passing into the outer layers of which the follicles are composed, there are involuntary muscles, which are called the erector muscles, by means of which the hairs are drawn into an upright position when acted on by the nerves. Their contraction also assists the sebaceous glands to discharge their contents. To their action also is due the mottled condition of the skin which we often call goose-skin, because it resembles

the skin of that bird when the feathers are plucked out.

The rudiments of the first hairs appear in the human fœtus about the end of the third month, the growth being just completed about the fifth or sixth month, and just as in mammals, are at first solid knob-like outgrowths of the stratum malpighi into the corium, especially of the deepest layers of columnar cells. In some instances the corium shows a slight elevation preceding the formation of the rudiment of the hair, but this is absent in many instances.

Development of Hair Follicle.—"The hairs are originally developed in the embryo in the form of small solid downgrowths from the malpighian layer of the epidermis. The hair-germ, as it is called, although it does not give rise to the hair but to the epithelial cells of the hair follicle, is at first composed of soft-growing cells, the outermost and deepest having a columnar shape. Presently those in the centre become differentiated so as to produce a minute hair invested by an inner root-sheath with its base resting upon a papilla which has become enclosed by the extremity of the hair-germ, and which is continuous with the connective tissue of the corium. As this minute hair grows it pushes its way through the successive layers of the epidermis, which it finally perforates, the epithelial layer being thrown off. At the same time the follicle grows more deeply into the corium and carries the papilla down with it."[1]

The origin and development of the follicle and the hair within the fœtal skin is most interesting and instructive, and will better be understood and followed by reference to Fig. 13, which represents a diagrammatic vertical section of the skin.

[1] *Essentials of Histology*, Schäfer, p. 239, Longmans, London, 1907.

A represents the outer skin or cuticle resting upon the stratum corneum which merges downwards into the stratum lucidum and the rete mucosum. The first metabolic change, which results in the formation of the hair-follicle, commences by the involution of the rete mucosum down through

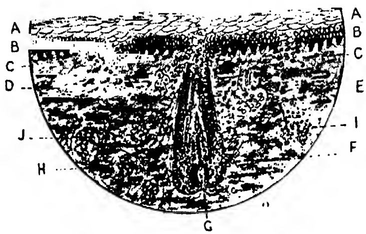


FIG. 13.—Hair-Germs and Follicles in Process of Development (Vertical Section). × 120 diameters.

A. Epidermis.
B. Rete mucosum resting on the papillary layer.
C. Primary involution of epidermis.
D. Germ cells of sebaceous gland.
E. Connective tissue cells accumulating to produce the dermic coat of follicle.
F. Developing hair follicle.
G. Papilla of follicle.
H. Rudimentary fat globules.
J. Cuticle of outer root-sheath in continuation of the basal membrane.

the papillary layer into the corium beneath, and which is represented at C. While this change is taking place, and which is only faintly represented by a dimpling in of the outer cuticle, an anticipatory metabolic change also commences, beneath this involutionary sac, in the lower strata of the corium, and which is indicated by the evolution of numbers of connective tissue cells, as seen at

E and I, which commence to group themselves symmetrically round an axial line passing through the centre of the epidermic depression at right angles to the surface of the skin, or nearly so. These cells gradually, as will be seen at I, form the nucleus of the root of the follicle with its basal layer and papilla, which is exhibited when more fully developed at G.

Meanwhile, the connective tissue in the strata above the top of the papilla has formed the rudimentary inner hair sheath or tube, and by the absorption into themselves of the enclosing cells have prepared a funicular space, which gradually extends upwards towards the involutionary sac of the rete mucosum, and within which the rudimentary hair commences to be formed by the generative cells now thrown off from the papilla.

This is the birth of the hair or wool fibre which is clearly seen in the diagram, and which, as it passes upwards, gradually increases in diameter as the plastic cells are crowded into it from below until it entirely fills the tube, while the cells assuming the medullary, cortical, or cuticular form, according to their position, constitute the fibre, whose more consolidated point, when it reaches the top of the inner root-sheath penetrates the overlying epidermic scales and thus passes out beyond the surface of the skin. In this follicle the sebaceous gland, with its duct opening into the side of the follicle, is seen in the process of formation by an outgrowth of the outer wall of the follicle. At F the marginal process is seen, to which the erector muscles are attached.

The rudiment of the hair rapidly elongating becomes cylindrical, and in it may be noticed the following elements: the majority of the cells are small and polyhedral, in the marginal layer they are hexagonal or slightly columnar, the

former possess a spherical, the latter an oval, nucleus; the cells and their nuclei in the axial portion of the hair rudiment are slightly flattened. There is a distinct limiting membrane between the marginal layer of cells and the surrounding tissue; this membrane represents the rudiments of the transparent basement membrane. Each of the hair rudiments is from the earliest time surrounded by a thick layer of tissue altogether different from the rest of the corium, and representing the rudiment of the hair sac; it is well marked off from the corium, is composed of a network of flattened, spindle-shaped or branched cells, and stains as a whole, with reagents, better than the rest of the corium; although relatively very bulky, it nevertheless can be traced directly to a thin layer similarly constituted and situated immediately underneath the epithelium of the surface, that is to say, a layer which gives origin to the papillary body of the corium.

There is a definite distinction between the hair sac and the surrounding corium in the full-grown hair, and we see this is borne out by the development. The branched cells of the rudiment of the hair sac soon make their way into the above solid cylindrical hair rudiment, and thus give origin to the branched nucieated cells that are present in the adult state between the cells of the outer root-sheath.

The tissue of the hair sac grows much more rapidly than the hair rudiment, and having closed round the deep extremity of the latter, grows now against it as the papilla, and thus produces the inflection and enlargement of the bulb.

Henceforth the multiplication of the cells at the bulb naturally leads to the new cells being pushed up in the axis of the hair rudiment towards the surface, and becoming elongated, constitute the elements of the hair substance and its cuticle and inner root-sheath. The cells of the

primary solid cylinder represent the rudiment of the cells of the outer root-sheath only. The gradual conversion of the cells of the bulb into the spindly-shaped horny scales of the substance of the hair, the differentiation at the bulb of the cell layers, and their conversion into the cuticle of the hair and the inner root-sheath are easily understood from the description given above of these parts of the adult hair.

One of the latest parts to appear is the mouth of the hair follicle, as the hair exists for some time beneath the skin before its appearance outside. The hair itself and the inner root-sheath, having reached the stratum corneum of the surface, for a short time continues to grow underneath it for a considerable distance, in a horizontal or slightly oblique direction; ultimately however the stratum corneum is broken through, and the mouth of the follicle having thus been established, the hair henceforth grows beyond the free surface, losing the adherent parts of the inner root-sheath from the neck outwards.

As soon as the rudiment of the papilla makes its appearance, the hair follicle, then still a solid cylindrical mass of cells, pushes out, near its connection with the surface epithelium, a small knob composed of the same polyhedral cells as the hair follicle; this knob gradually elongates, divides at its extremity, and its branches are converted into the alveoli of the sebaceous gland. This duct is, therefore, an outgrowth of the neck of the hair follicle.

Fœtal Hair.—The fully developed fœtal hair is very thin, and its follicle and papilla do not reach the subcutaneous tissue. These fine hairs form a complete covering over the whole surface of the body, except the palms of the hands and the soles of the feet, termed the *lanugo*, which is replaced in many localities, soon after birth, by a much

coarser hair, whose follicle and papilla pass down into the depth of the subcutaneous tissue. This new hair is produced from the outer root-sheath of the primary hair follicle, as will be presently described.

Bed-hair.—Every hair in the young child, as well as in the adult, sooner or later undergoes a peculiar change, which leads to the formation of Henle's hair knob, or the intercalated hair of Götte, or the bed-hair of Unna, differing in several important respects from the normal or perfect hair, and called by Unna the papillary hair. The mode of change of the latter into the bed-hair is the following: The cells of the bulb, over the papilla, cease to multiply, and consequently the hair and its inner root-sheath stop growing, first the inner then the outer root-sheath atrophy, but the root of the hair remains connected with the papilla for some time by a thin streak of cells, ultimately also this disappears. This process of atrophy extends up to near the point where the erector pili is attached to the hair sac; here the external root-sheath becomes conspicuously enlarged, and the hair root terminates in it with Henle's hair knob, being an enlarged broomlike extremity, which, with its fibrous horny elements, branches out amongst the adjacent cells of the outer root-sheath. The inner root-sheath is wanting just at the extremity, but is met with at a short distance higher up. The hair continues to grow at its knob, at the expense of the adjacent flattened cells of the outer root-sheath, and in this condition, viz. as a bed-hair, it may retain its position and existence for a considerable time. In many instances it is, however, eliminated spontaneously, or by the growth of a new hair, produced from the cells of its (viz. the bed-hair's) outer root-sheath.

As mentioned previously, this part of the external root-

sheath, viz. about the region of attachment to the erector muscle, contains on its surface sometimes few, sometimes many, smaller or larger knob-like or cylindrical solid projections of epithelial cells. Now, in some instances, one of these grows into the depth as a cylindrical solid cell-mass, either making for itself a new path, *i.e.* becoming provided with a new hair sac, or advancing in the path of the former hair; this is the rudiment of the outer root-sheath of the new hair. Its extremity becomes inflected over a new papilla, just as was the case in the fœtal process. The cells of this inflected part rapidly increase in numbers, and thus form the bulbous extremity in connection with which the hair itself and its inner root-sheath are formed in exactly the same manner as in the embryo. Now the new hair, as it grows upwards in the axis of the new outer root-sheath, either passes altogether at the side of its bed-hair and ultimately reaches the surface, its follicle becoming provided with a new neck and mouth, or it makes its way into the follicle of the bed-hair. In this case the hair knob, being pressed by the pointed extremity of the new hair, is gradually pushed upwards towards the free surface, and finally is altogether ejected.

Hair follicles with two hairs, one an old hair and the other a young newly formed papillary hair and growing from the depth, are to be explained in this manner.

Stieda exhaustively proved the degeneration of the old papilla and the formation of the new one; Feiertag, Schulin, and especially Unna by his elaborate and careful researches, fully established it.[1]

Modification of Hair.—As already remarked, the hair is capable of considerable modification under various conditions. This is indeed a peculiarity of all epidermal growths,

[1] Klein's *Atlas of Histology*, pp. 325-327.

as will very readily be recognised when we remember that the nails at the extremities of the toes and fingers, and in quadrupeds the hoofs of the feet, and even in some animals such excrescences as the horns on the head, have a common origin.

In the hair, one of the commonest variations consists in a waved character being imparted to it, so that instead of standing out stiff and erect it possesses a curly nature. This can be imparted to all ordinary hair by the application of heat and pressure, but it speedily passes away when these artificial means are removed. This arises from unequal contraction in different parts of the hair. Under variation in climatic condition the hair tends to assume this character, and it is very well seen in the hair of the negro, which has far more the appearance of wool than hair. This likeness does not, however, exist further than the mere curl is concerned, because a microscopical examination of the hair of the negro clearly demonstrates that it possesses the same structure as that of the European. Moreover, even this woolly character is not constant in the negro race, because different classes present every gradation from a full woolly lock down to a curled or even flowing hair. The true distinction between wool and hair lies in the nature of the epidermal covering with which the cortical part of the shaft is covered, and in the method of attachment of the scaly plates or flattened cells to the inner layer upon which they rest, and not upon the curly nature of the whole fibre itself, although there can be no doubt but that this waved appearance is one of the recognised characters of wool. There are, however, to be found numerous hairs which possess no curl, and yet have the epidermal characteristic of a true wool, which consists in the power to felt or mat, arising from the greater looseness of the scaly

covering of the hair, and which, when opposing hairs come into contact, enables these scales to interlock into each other, and holds them together quite independent of any friction or twist imparted to the fibre by mechanical means. This peculiar characteristic will be more readily understood by looking at Fig. 14, where we have an imaginary longitudinal section of a typical wool fibre opposed to another similar fibre, so that when they are drawn along over each other the scales interlock, serration into serration, and thus become perfectly united together by the wedged edges of the scales entering into the spaces between the scale and shaft of the opposing fibre.

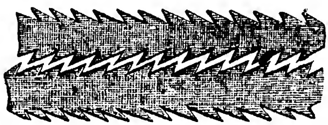


FIG. 14.—Interlocking and Felting of Wool Fibre.

Felting of Hair.—It has been seen that in the case of human hair the free edges of the scales are always pointed upwards towards the unattached end of the hair. This is also the case in wool, and when it is in its proper position on the back of the animal, quite independent of other causes which we shall afterwards have to name, the scales of the woolly hair are all pointing in the same direction, so that their tendency to mat or felt is reduced to a minimum, otherwise the fleece or pelt of the creature would become one matted tangled mass. The scales being in the same direction, the hairs have the tendency to slide over each other without interlocking, and thus prevent the disagreeable results which would otherwise occur.

Typical Wool Fibre.—Fig. 15 is a representation of what may be considered a typical wool fibre, and by comparing it with Fig. 10 the great difference between the wool and the hair is clearly seen. In the wool the cylindrical or cortical part of the fibre is entirely covered with very numerous lorications or scales, the free ends of which have a pointed rather than a rounded form. This enables them more readily when opposed to each other to find their way

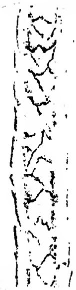


FIG. 15.—Typical Wool Fibre. × 160 diameters.
Showing the pointed and serrated edges of the epidermal scales when treated with caustic soda.

under opposing scales, and to penetrate inwards and downwards proportionate to the pressure which is applied to bring them together. In the wool fibre the free margins of the scales are also much longer and deeper than in the hair, where the overlapping scales are attached to the under layer up to the very margin of the scale, which can, at its extremity even, only be detached by the use of a suitable reagent. In wool this is quite unnecessary, because the ends of the scales are free to about two-thirds of their

length, and are to a certain extent, indeed, turned partially outwards, as can readily be seen by looking at the edges of the wool fibre, Fig. 15, where the denticulated structure is quite distinct against the dark background. This ideal diagram approaches nearer to the fibre obtained from the wool of the merino sheep than any other. This is one of the most valuable and beautiful wools which is grown, and one which, either pure or mixed with other breeds, yields a large proportion of the wool which is used in our best manufactures. It, then, may be taken as the typical wool fibre, and it will be found that just as the mechanical structure of any wool approaches this standard it becomes better and better fitted for textile purposes, and just as it departs from it does it become less useful and less fitted for those peculiar uses to which wool can be put. In different classes of sheep every variety of intermediate structure occurs between true hairs and the fullest development of the woolly nature of the fibre, and under certain conditions these wide differences may even exist in the fibres taken from the fleece of the same animal; and just in proportion as the conditions surrounding the sheep are favourable to the finest development of all its best qualities, and in proportion as the purity of the breed is maintained, does the production of hairy fibres diminish and true wool replace them. Other fibres besides those which are grown upon the sheep also partake of this peculiar property, but none possess it so universally and so uniformly. Even the wool of the sheep is subject to great differences in this respect, arising from a variety of causes, and hence the great necessity for studying these causes, so that by suitable selection and cultivation we may be enabled to produce the best and most uniform raw material. However correct the mechanical processes of spinning may be, as has

already been seen when looking at the cotton fibre, we can never get beyond the degree of uniformity which is manifested in the raw material itself, and this is equally true as regards the wool fibre also. Perfectly uniform material to work upon is the basis of perfect spinning, and although we can never expect to reach this standard, there is no limit assigned to the nearness with which we may approach to it. Every step taken towards this end is a step in the right direction, and a knowledge derived from observation and experience of what is required is the only basis upon which to work. Hence the typical fibre becomes invested with a deeply practical as well as theoretical interest, and forms the key to all future progress and success, and in the next chapter, therefore, it is necessary to look shortly at some variations in the wool fibres of the various classes of sheep which are found in the different quarters of the world, so as to understand the nature of the conditions to which they are likely to be subjected, and prepare for a closer study of their different and characteristic fibres as they are affected by these conditions, and see how far they fit or unfit them for use in textile manufactures.

CHAPTER V

VARIATION IN HAIR STRUCTURE

As has already been seen in the previous chapters, the variation in the structure which is assumed by the hair-like appendages of the skin is very great, and differs not only in the hairs found upon different animals, but also in those found on the same animal in different parts of the body.

The modification which the hair undergoes may occur in every part of its structure, in which case it may cause an entire transformation, as in the case of the feathers and claws of birds, the hoofs and horns of animals, and the nails on the hands and feet of man. In hair the differences are usually shown in the medullary and cuticular portions, while in wool the greatest variation occurs in the entire disappearance of the medulla and such modification of the cuticle as renders the hair more supple and the capacity for felting greater.

In attempting a general classification of hairs it is best to arrange them under heads which do not depend strictly upon their histological distinctions, but upon their length, strength, stiffness, and distribution upon the body of the animal, and under such an arrangement they may be divided as follows :—

1. *Bristles*, or short, stiff, strong, elastic hairs, of which those found on the hog, and especially when in the wild state, are typical examples, where the structure is almost solid and the medulla inconspicuous.

2. *Bristle-hairs*, which are short and stiff, and always exhibit a medulla, and which usually occur either in isolated groups on particular parts of the body, such as the eye-lashes and vibrissæ of the carnivora, or, as in the case of the horse, forming a stiff erectile coat covering the whole surface of the body.

3. *Beard-hairs*, which are long and straight, but sometimes wavy, and generally exhibiting a medulla or traces of one, and which characterise the skin of most animals which are hair-bearing, such as the cat, dog, seal, otter, and similar creatures, and in the horse forming the mane and tail, and in the straight-haired races of man, the hair of the head.

4. *Wool*, which is the modified hair found on the goat and sheep—in the goat generally constituting an under-growth of fine curly fibres, and in the cultivated sheep comprising the whole fleece. Here the medulla is entirely bred out, and the cortical portion constitutes the whole substance of the shaft, while the cuticle is formed of exceedingly thin, flat, and numerous imbricated cells, more or less ring- or cup-shaped, enclosing the cortex as a flexible sheath.

Wool is, however, only one of a numerous class of similar fibres which are modified growths of the epi-dermal covering of the higher animals, and we looked specially at the case of human hair, because more is known of its histology than that of any other fibre. In the human hair it was found that when treated with an alkaline ley, and examined under the microscope, the whole surface of

the hair was covered with a series of fine, delicate, epidermal scales, which under ordinary circumstances are attached close to the shaft of the hair, and correspond to the scales of the scarf skin on the surface of the body. In the case of wool, it was seen that the surface of the shaft of the fibre was also covered with scales, but that in proportion to the diameter of the fibre they were stronger and less numerous; they also bend outwards from the shaft of the fibre, at a higher angle, and hence possess a serrated edge, which always presents the points of the scales in the direction of the growth of the fibre, that is to say, from the base upwards to the point. When, therefore, two fibres are reversed in position, and drawn over each other in the direction of their length, so that the point of one hair touches the base of the other, these scaly edges interlock into each other, and a matting or felting is the result; the tenacity with which they can hold together being limited only by the strength of the fibres themselves. In the case of wool this matting action is much increased by the tendency of the fibres to assume a waved or curly structure, which enables them to wrap round each other, and thus form a firm, tenacious mass. Although the true cause of the curl in wool is not yet known, still there seems to be a close relation between the tendency to curl, the fineness of the fibre, and the number of scales per inch on the surface. This is very clearly shown in a series of experiments recorded by M. Lafoun in the *Annales de l'Agriculture Française*, 1832. The experiments were made with the wool of some German Merino sheep, at Hohenheim, in Würtemberg, and Schleisheim, near Munich. Three times a year the whole of the flock was inspected, (1) before winter, when the selection of the lambs is made, (2) in the spring, and (3) at the shearing time. Each sheep

was examined separately, and the examination included the length, pliability, brilliancy, and fineness of the wool. The latter property, which is measured by the diameter of the fibre, was ascertained by actual determination with the micrometer. It was found that this fineness differed in different parts of the fleece, as we might reasonably expect; and when the wool in the fleece was sorted into its different qualities, in the manner usual in France, the results are given in the following table:—

No.	Quality.	Curls or Curves per Inch.	Diameter of Fibre.
1	Super-Electa . .	27 to 29	$\frac{1}{840}$th of an inch.
2	Electa . . .	24 ,, 28	$\frac{1}{735}$th ,,
3	Prima . . .	20 ,, 23	$\frac{1}{660}$th ,,
4	Secunda Prima .	19 ,, 20	$\frac{1}{588}$th ,,
5	Secunda . . .	16 ,, 17	$\frac{1}{534}$th ,,
6	Tertia . . .	14 ,, 15	$\frac{1}{510}$th ,,
7	Quarta . . .	12 ,, 13	$\frac{1}{470}$th ,,

It will be seen in this table that the finer the wool the greater the tendency to curl; for when the diameter of the fibre is $\frac{1}{840}$th of an inch, the number of curves is more than double that which pertains to the fibres whose diameter is $\frac{1}{470}$th of an inch.

The same variation can be seen if we compare the curves and diameter of the fibres in the wools of our own country, as will be seen from the following table:—

No.	Name.	Curves per Inch.	Diameter of Fibre.
1	English Merino .	24 to 30	$\frac{1}{1562}$nd of an inch.
2	Southdown . .	13 ,, 18	$\frac{1}{1273}$nd ,,
3	,, . .	11 ,, 16	$\frac{1}{1000}$th ,,
4	Irish . . .	7 ,, 11	$\frac{1}{830}$th ,,
5	Lincoln . . .	3 ,, 5	$\frac{1}{640}$th ,,
6	Northumberland .	2 ,, 4	$\frac{1}{580}$th ,,

As already stated, the growth of serrated fibres is not confined to the sheep alone, but is very widely diffused in the animal kingdom. Almost all the higher mammals have a hairy coating of some kind or other, and in by far the largest number we find a tendency to produce an undergrowth of fine woolly fibre, especially during the colder seasons of the year. The difference which exists between the hair of man and that of the lower animals consists really only in a different proportion of size and arrangement in the cells composing the different parts of the fibre, as well as in a greater or less development of the scales or plates which form the epidermal covering. When viewed under the microscope, the hairs and wool of different animals present, therefore, a great variety of structure and appearance, especially when seen by transmitted light, which brings out the arrangement, structure, and grouping of the cells in the interior of the fibre. So far, however, as our present subject is concerned, we are more especially interested in the external covering, and here the differences are equally well marked. Fig. 16 gives a representation of various hairs from the kangaroo, camel, rabbit, and *Ornithorhynchus paradorus*, a singular animal found in Australia, which has a head terminating in a bill like a duck.

In looking at these hairs we see how diverse is the structure. In the kangaroo the scales are quite distinct and imbricated, and stand off from the surface of the hair with a wonderful regularity of arrangement. In the camel's hair we find an approximation to the appearance of true wool, where the scales take the form of irregular loricatìons on the surface of the hair, and the upper edges of which separate from the face of the shaft when the hair is bent, as well as felt when they are met in the opposite

direction by similar opposing scales. The hair of the Ornithorhynchus presents a very much finer imbricated surface, but with the same general structure; while in the hair of the rabbit we have a series of laminated plates which rise from between the more solid parts of the cortical substance, which exhibits large distinct semi-transparent cells. We might almost indefinitely extend the list of

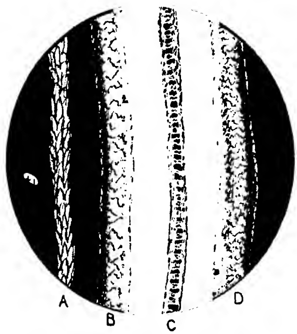


FIG. 16.—Various Hairs magnified. × 100 diameters.

A. Hair of Kangaroo. C. Hair of Rabbit.
B. Hair of Camel. D. Hair of Ornithorhynchus paradoxus.

different hairs, but these will suffice to show some of the variations which are found.

Although in wool the variations are not so great as those exhibited in the fibres of these different hairs, still they are very marked, and some of them are of considerable significance.

These variations in the fibres taken from the same animal and growing side by side at the same time are very instructive, and indicate the extreme plasticity of these

epidermal growths. Such divergent contemporaneous forms are generally associated in the fleece of the semi-wild sheep of the mountainous regions of Central Asia and the adjacent plains of Tartary and Siberia, and the general character of the pelt is coarse and irregular, defaced by strong beard-hairs, mixed with a fine undergrowth which fills up the spaces in the skin between the coarse hairs like grass amid a tangle of undergrowth. In some of these wools, such as grey Vicaneer, dark Bagdad, and yellow Pacpathian, we have several distinct classes of fibres side by side in the same fleece. The fleeces of these sheep indeed exhibit a greater variation in the structure of individual fibres than any others which have come under observation. These fibres may in the same fleece, and often in the same lock of wool, be roughly divided into three different classes:—

(*a*) Those which have all the characteristics of true hair in their most marked degree.

(*b*) Those which resemble alpaca and mohair fibres.

(*c*) Those which are true wool.

In the first of these divisions (*a*) there are several distinct variations in the form of the hair structure. In Fig. 17 the internal structure is illustrated of one of these fibres taken from a Pacpathian sheep, as shown at A, and its resemblance to a hair will be seen at once. The external appearance of many of these fibres is remarkable for the very great regularity in the arrangement of the external scales, and by their pointed extremities, which gives them almost the appearance of the stem of a palm-tree. B gives an illustration of one of these fibres, which was taken from a lock of Bagdad wool. Occasionally this great regularity in the epidermal scales is found in the hairs of more cultivated sheep, as may be noticed at A,

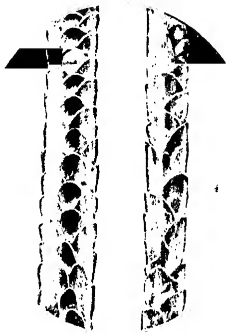
Fig. 18, which is sketched from the surface of a coarse hair from the fleece of a Cheviot sheep. Sometimes the construction of the cuticular layer of these coarse hairs tends to the production of larger scales than those which are usually found on other associated fibres. These scales present an appearance as though the larger scales had

FIG. 17.—Section and Surface of Coarse Asiatic Sheep's Hair. × 135 diameters.

A. Section of Pacpathian sheep's hair seen by transmitted light.
B. Surface scales of Bagdad sheep's hair seen by reflected light.

been formed within the follicle by the coalescence of several smaller scales into one, and it is specially noticed that in cases where this occurs there is a tendency in the free edge or margin of the large scale to follow the same contour as the smaller ones. Sometimes there are slight surface markings or depressions on the larger scales, which seem to indicate the margins of the smaller ones out of which they were formed. The union is, however, so com-

plete that it is impossible, except in a very few instances, to separate the larger into the smaller scales, even by the use of reagents. In Fig. 18, at B, is sketched a coarse hair of Pacpathian wool, in which the surface markings of many of the large scales show the configuration of the smaller scales out of which they were formed. Occasionally the whole epidermal tissue of these coarse hairs assumes an



A B

FIG. 18.—Coarse Hairs showing Regular Scales. × 150 diameters.

A. Coarse hair from large Cheviot ram. B. Coarse hair from Pacpathian sheep. Both seen by reflected light.

entirely different appearance, in which the usual scaly structure is replaced by a series of interrupted longitudinal channels, which give the fibre the appearance of a vegetable rather than an animal structure. One of these fibres, taken from a lock of Jora wool, is given in Fig. 19, at A, in which the cuticular envelope resembles a fluted column; and where any transverse lines are present to mark the free margins of the scales, they not inaptly supply the semblance

of joints in the masonry. In all cases where this peculiar structure is visible in the cuticular layer, there is associated along with it an equally distinctive cortical and medullary formation. The cortex exhibits a coarse texture of spindle-shaped cells with longitudinal striæ, while the medulla is composed of large and distinct rounded cells with well-marked nuclei. The whole arrangement is indicative of a


A B

FIG. 19.—Fibre of Jora Wool-hair. × 120 diameters.

A. Fibre seen by reflected light. B. Section of fibre seen by transmitted light.

loose formation, with considerable air spaces existing both in the medulla and cortex. B represents the internal structure of the fibre whose external surface is given at A. Probably this extreme variation from the normal type may have arisen from the shrinking up of the loosely packed cells in the cortical part, which by their attachment to the epidermal layer, which seems to be thinner than is usual in hairs of this diameter, have drawn them inwards, and thus

formed corrugations at the intervals between successive bundles of the elongated cells.

The second class of fibres (*b*) have a very close resemblance to those of alpaca and mohair, but they are usually softer and more pliant, with less lustre and a greater tendency to variation in the formation of individual scales in the cuticular layer. One of these fibres, taken from a lock of

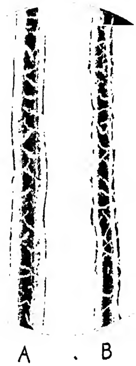


FIG. 20.—Wool-like Fibres of Pacpathian Sheep. × 120 diameters.
A. Coarse fibre like alpaca. B. Fine fibre like coarse wool.
Both seen by reflected light.

Pacpathian wool, is given at A, Fig. 20, and cannot be distinguished from a fibre of alpaca, such as that given in Fig. 57, except by its association with other fibres which never occur in the fleece of the alpaca goat. Other fibres, however, approach very closely to the appearance of true wool, but with a greater variation in the regularity of the individual scales than is usual in the more cultivated sheep. B is an illustration of one of these fibres taken also from a

Pacpathian fleece, which may be compared with the French Merino fibres given in Fig. 71. Among these fibres we also notice the first indication of a surface formation, which is a very common variation from the typical form in the more cultivated wools. This consists in a tendency to form rings of scales, in which we have a single scale continuous round the whole circumference of the fibre, similar

Fig. 21.—Fibres taken from a Pacpathian and an Afghan Sheep. × 120 diameters.

A. Ring-scaled fibre from a Pacpathian sheep. B. Fine undergrowth fibre from Afghan sheep.
Both seen with reflected light.

to those characteristic of Chinese wool given in Fig. 59, and in the Indian wool, Fig. 60, except that the free margin of the scales are not so marked or the scales so solid and horny, while the attachment of the epidermal scales to the cortical part is more continuous. Such a fibre is given at A in Fig. 21, taken from a Pacpathian fleece.

The third class of fibres (c) are those of true wool, and

possess all its highest characteristics. They are always much shorter than the others, and form an undergrowth of fine fibres which fill in the spaces between the coarser hairs, and in many cases are as fine and delicate in structure, with as great a tendency to curl, as the most beautiful fibres taken from the fleeces of the most cultivated sheep.

The illustration B represents a fibre drawn from the fleece of an Afghan sheep (*Ovis cagia*). The specimen of wool from this sheep was a most extraordinary mixture of the very coarsest hair and fibre with the very finest wool, so much so that it almost seemed impossible that such diverse fibres could grow at any rate on the same portion of the skin. Most of the coarse hairs resembled B in Fig. 18, and were deeply coloured by dark, black, brown, and yellow pigment, and possessed a hard, horny structure. The fine fibres were perfectly colourless and transparent, and closely resembled the wool of the English Southdown (Fig. 65) or the Australian Botany Merino (Fig. 73). Except that there was a greater variation in the structure of the scales in many of the individual fibres than is usually noticed in the most cultivated wools, they could hardly be distinguished from them. When we come to look at the wool of the more cultivated races of sheep, such as the common domestic sheep (*Ovis rusticus*), we find much less variation in the individual fibres than is usual in the less cultivated races, but the difference in structure between one fibre and another is nevertheless frequently very marked.

If we examine a number of fibres from a Lincoln sheep, there is in the finer fibres a close resemblance to those which are found in all the long-woolled breeds, but along with these there are fibres which are distinctive of the Lincoln breed alone. In the latter there occur more or

less rounded scales along with the usual serrated ones, as though there was a tendency to revert to the more distinct form of scales which are seen on some of the coarser hairs, such as given at A, Fig. 18, from a Cheviot sheep, or the alpaca-like fibre given at A in Fig. 20. Many parts of this fibre bear a distinct resemblance to the Lincoln fibre given, except that the scales are not so distinctly marked nor so freely imbricated at the margins, and at irregular intervals this imbrication entirely ceases, and we have smooth rounded edges taking their place. When looking at the second class of fibres found in the coarse Asiatic wools, we noticed a formation represented at A in Fig. 21 where the scales lose their foliated character and tend to form continuous rings. This peculiarity in the formation and attachment of the cuticular scales is frequently found amongst the fibres of the more cultivated wools.

It is indeed of very frequent occurrence in most of the long-woolled breeds, such as the Lincoln, and may be seen at A and B, Fig. 51, which represents the appearance of a fine fibre taken from a fine Lincoln wether fleece. Where this formation obtains, the scales are always more horny in their substance than those of the fibres possessing the normal structure which are associated with them. In many cases these fibres are found in clusters in the lock of wool, as though a special area of the skin possessed the power of producing them; but they are also frequently found separately, and sometimes only parts even of the same fibre exhibit this peculiarity. They are also usually confined to certain parts of the animal, and occur specially at those parts where the wool tails off into short hair, as at the junction of wool and hair on the face and limbs.

Kemps.—At A, Fig. 22, is seen a fibre which displays both the characteristic scales of the true wool and the larger and more ring-like formations. This was sketched from a fibre taken from a Lincoln sheep. In this fibre it will be noticed that one of the ring-like scales is of great length when compared with the diameter of the fibre

A . B

FIG. 22.—Lincoln Wool Fibre and Longitudinal Section. × 120 diameters.

A. Fibre seen by reflected light, showing large ring scale.
B. Same fibre seen by transmitted light, showing discontinuance of medulla.

or the relative length of the other scales above and below. When this fibre was examined with transmitted light, so as to render its internal structure visible, a peculiarity was noticed which is of very great importance from an industrial or technical point of view. At that part of the fibre where the surface was covered by a large smooth scale, the internal structure exhibits no sign of any definite

cells, either in the medullary or cortical parts. Up to the extremity of the imbricated and wool-like scales indications of cell structure are visible, both in the cortical and medullary parts, but beyond that point they cease to exist in either, and the whole fibre assumes an ivory-like density. This change in structure does not occur all at once, but seems to commence in the central part of the fibre, and gradually to extend outwards until it constitutes the formation of the whole fibre. This will be seen at B in Fig. 22, which exhibits a section of the same fibre. Beyond the point to which the ring-like scale extends, this solid structure again tails off, and the fibre assumes its usual appearance. This peculiarity is not of very great importance when the area over which it extends is small, but when it becomes the general characteristic of the fibre it introduces serious difficulties in the way of the manufacturer, because the solid portion of the fibre ceases to be elastic and pliable, and easily breaks when subjected to flexure. In addition to this, all these fibres resist, or are incapable of, that felting action which is so important a feature in the true wool, and which depends upon the facility with which the scales of the one fibre interlock into those of others when in juxtaposition. These solid fibres also resist the entrance of all dyeing or colouring matter into their interior, and will only receive a surface colouring, which is readily removed by either chemical or mechanical means. In some cases the outer continuity of the scales is not accompanied by a change of internal structure, and when examined by transmitted light the cortical and even medullary cells are distinctly visible. Such fibres are usually known as oval kemps, because they generally possess an oval section in which the major axis is very large in comparison with

the minor axis. In this case the fibres will receive the dye, but will not felt.

True kempy fibres are always most numerous in the fleeces of wild and uncultivated sheep, but they also occur in those of the most cultivated races. In the former case they are generally distributed throughout the whole of the fleece, but in the latter they are usually confined to certain localities, as already mentioned, and are almost certain indications of want of trueness in the breed of the sheep. These kempy fibres are in most cases larger in diameter and shorter in length than the wool fibres with which they are associated. They are coarse and brittle, exhibiting no internal structure, and oftentimes, when examined with a low power, show longitudinal markings which seem to indicate they were formed by the coalescence of several hairs, in the same way as in the formation of the nails of the hand. Fig. 23 represents at A the surface of a coarse flat kemp taken from a Highland sheep, and at B a transverse section.

In the fibres taken from the fleeces of middle-classed wools, such as the Southdown and half-bred sheep, there is considerable uniformity in the general structure of the fibres and the surface configuration of the scales, but with frequent indications in many of the fibres of a return or reversion to the typical fibres of the original stocks out of which these artificial races have been produced. A and B, Fig. 24, are illustrations of two fibres taken from the same lock of wool drawn from a Leicester-Botany fleece. The first exhibits all the characteristic features of the fibres found in a pure Leicester sheep, and the latter closely resembles the pure Australian Merino fibres as shown in Fig. 73. These two fibres must, from their position in the lock of wool from which they

were taken, have been generated in follicles which were embedded side by side in the skin. They may be compared with Fig. 62, which represents the fibres of Leicester wool, and 69, which is taken from pure American Vermont Merino.

In the perfectly pure races of sheep, such as the best English Southdowns, or the Spanish, French, German, and Australian Merinos, in which we find the greatest perfec-

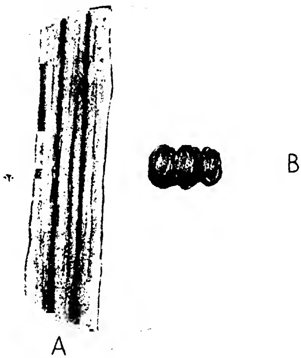


FIG. 23.—Flat Kemp from Highland Sheep. × 75 diameters.

A. Showing longitudinal markings.
B. Section showing appearance of coalescence of three fibres.

tion of the fleece and fibre in all the most desirable characteristics of wool, and where every care and attention has been paid to the health and comfort of the sheep, we also find the least tendency to any variation in the individual fibres. Even here, however, there are sometimes found differences in the structure of fibres which have grown in close contiguity with each other. This difference can only be explained by considering some of

the arrangements of the epidermal scales as undoubted cases of reversion to the type of fibre characteristic of the original stock from which these varieties were obtained in the remote past. Several of these more important variations are given in Figs. 24 and 25. These fibres are all sketched from pure Australian Merino fibres. A in

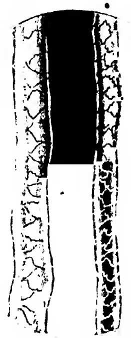


FIG. 24.—Fibres of Leicester Botany Wool. × 120 diameters.

A. Fibre showing character of Leicester stock.
B. Fibre showing character of Merino stock.
Both seen with reflected light.

Fig. 25 shows a fibre where the arrangement of the epidermal scales in the upper and lower part closely resembles that exhibited in the Cheviot fibres given at A in Fig. 18, while the central portion is covered with scales which are similar to those on the Pacpathian fibre, given at B in Fig. 17. The fibre given at B, Fig. 25, closely resembles the fibre A, Fig. 22, taken from a Lincoln sheep, in which the same ring-like scales appear

at intervals. C shows a kempy development, similar to B in Fig. 22, which, however, in the finest Merino wool is very rare, with short intervals in which the true wool appears. As a rule, when kemps occur in the Merinos, the whole fibre partakes of this character, and the fibres are oval in section with a clear transparent

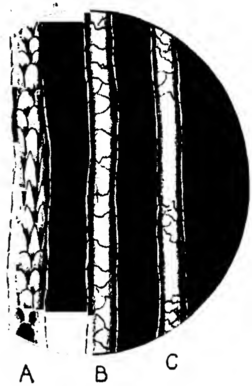


FIG. 25.—Fibres of pure Australian Merino. × 120 diameters.

A. Fibre with rounded and lanceolate scales. B. Fibre with ring-scales. C. Fibre with long continuous ring scales.

structure. In some of these kempy fibres the usual curled or waved character of the true wool is replaced by a twisting of the whole fibre round its axis, so as to give the appearance of a corkscrew with a comparatively wide pitch, or like the twist in a fibre of cotton.

There is often also, even in cultured sheep and under certain conditions, a tendency to form abnormal fibres in the fleece, which may affect its use for manufacturing

purposes, either by interfering with its evenness, and so, by causing a change in its mechanical structure at certain points, making it weaker, or, by enlarging the diameter and increasing the volume of the cortical substance in this part of the fibre, so that it will not receive the same twist in the spinning or absorb the same quantity of dye-stuff, causing irregularity in the yarn and unevenness in the dye.

On this point Professor M'Murtrie of the Illinois Industrial University, in his report to the Commissioner of Agriculture (Dept. of Agriculture, Washington, 1886), remarks as follows:—

"It is the result of two causes, the one atrophy of the fibre at certain parts, the other hypertrophy. In some cases we find a sudden contraction of the fibre at certain parts (atrophy), and this is often sufficient to give a notched edge to the fibre. In other cases the contraction is more gradual, the progressive diminution in the diameter of the fibre extending over a considerable length."

This will be clearly seen in Fig. 26, where in fibres A and C the sudden transition is distinctly seen giving the notched appearance, and at B and D the gradual change continuing throughout a considerable portion of their length. These fibres are from an Oxford Down sheep.

In the enlargement (hypertrophy) such sharp variations do not occur, although they are generally found in the same fleece, and the fibres usually present a distinct variation from the normal fibres by either having this thickening in varying succession in the length of the fibre, or may have this variation, when once occurring, extending afterwards throughout the whole length of the fibre.

Fig. 27, also taken from an Oxford Down sheep, shows this peculiarity very distinctly in all the three fibres A, B,

and C, most marked, however, in C. It will also be noticed that when this thickening occurs, as in C, the scales depart from the imbricated ring shape in the fibre A, which is characteristic of the Southdown sheep, and tend to assume the larger and more rhombic form of scale which is characteristic of the long-woolled sheep, such as the

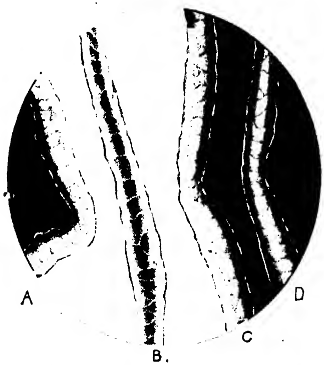


FIG. 26.—Fibres of Oxford Down Wool. × 150 diameters.

A. and C. Fibres showing rapid atrophy with notch.
B. and D. Fibres showing gradual atrophy.

Lincoln and Leicester. This is specially noticeable in the upper part of the fibre C.

Even in the still finer breeds of sheep, such as the carefully tended and nurtured Merino sheep, this frequently occurs, and has most importance and greater influence on the value of the fleece. It seems to pertain, not generally in the whole flock under the same conditions, but to certain individuals, and these sheep should be carefully

weeded out; but their occurrence is fortunately rare in the best stud flocks. It is more frequent in the fleece of the ewes, and especially those which are constitutionally weak or nervous, rather than in the rams, and there can

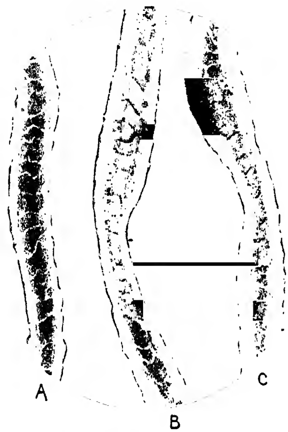


FIG. 27.—Fibres of Oxford Down Wool. × 200 diameters.

A. Fibre showing gradual hypertrophy.
B. Fibre showing less gradual hypertrophy.
C. Fibre showing rapid hypertrophy.

be little doubt that want of nutrition, exposure, or impaired health are contributory causes.

A fevered condition of the system tends to disturb the normal exercise of the functions of the organism, and specially such delicate parts as the appendages of the skin, and by the relaxation of the nervous tension result in atrophy or its contrary. If the fibres of breeding ewes are examined, there is in many instances indication more

or less marked of these variations being almost always present, because at this time the action of the organs connected with the generative function is not normal.

Fig. 28 shows four fibres taken from the coarsest part of the fleece of a Merino ewe, which illustrates this tendency to vary periodically, very marked in the fibre C. A shows

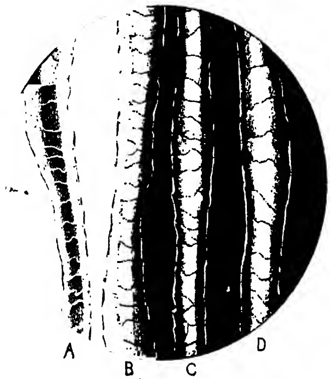


FIG. 28.—Fibres of Wool from Merino Ewe. × 375 diameters.

A. and C. Fibres showing gradual hypertrophy.
B. Fibre showing gradual atrophy.
D. Fibre showing gradual hypertrophy, with enlarged tabular scales.

the greatest variation, although B and D are equally instructive.

At any rate, there is sufficient evidence to indicate that when animals are well fed and cared for, and when the health of the flock has been uniformly good, these variations reach a minimum. Professor M'Murtrie gives the following instance: "A prominent breeder of Merino sheep

submitted a sample of his wool to determine its fineness. By the system of measurement followed we found that the fibres were finer at a certain part or point in their development than at others, and by simple calculation it was easy to determine at what part of the season the finer portions of the staple were developed. He stated that at that season the animal must have been in ill-health,

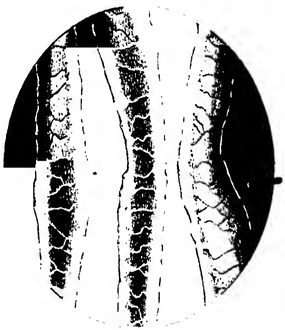


FIG. 29.—Fibres from a Lincoln Ewe. × 300 diameters. Showing atrophy and hypertrophy.

and this was found to be the case by reference to the record of the different individuals during the year."

This is also clearly marked in even the large long-woolled sheep, and Fig. 29, which exhibits three fibres taken from a Lincoln ewe, can be compared with the three preceding, Figs. 26, 27, and 28.

These variations from the normal structure of wool and other allied fibres might be very much increased if we include those which are evidently the result of malforma-

tions arising from the various diseases to which sheep are subject, or to the existence of more than one fibre within the same follicle, which frequently produces fibres of singular configuration, but those which have already been named and figured show the principal variations which are presented in the fibres under ordinary conditions.

It is singular that most of these variations, indeed all of them, are formed in the fibres from the same sheep in the various races which inhabit Central Asia; while in most of the sheep inhabiting other parts of the world the usual variations from the normal types are less distinctive in character, and confined within narrower limits. This seems to point to the mountainous regions of Central Asia as the district from which the present domestic sheep has spread over the other countries of the world. If the study of these variations will throw any light on the cause which produces them, and thus enable those who are engaged in the culture of the sheep to secure still greater uniformity in the character of the fleece, it will undoubtedly render great service to those who require to use wool for the higher branches of textile manufacture.

CHAPTER VI

HISTORY, CLASSIFICATION, AND VARIETIES OF SHEEP AND GOATS

HAIR and wool being appendages of the skin of the higher vertebrates, it is necessary to look at the character and peculiarities of these animals, since their nature, habits, and environment largely influence the structure of their pelt or fleece. The division of the animal kingdom which yields the true wool, and the most serviceable hair for manufacturing purposes, is the natural order Ruminantia, so called because they all ruminate or chew the cud; and in this class are included goats, sheep, and camels.

The typical wool is produced by the sheep, and its present state of perfection is due to the unremitting attention which has been paid to its cultivation so as to produce the highest and best characteristics of which it is capable.

History.—The ancestors of the sheep, like all the domestic animals, and indeed of all the present race of animals living on the earth, are lost in the obscurity of the past.

Long before the dawn of authentic history, and when

those of the fiercer animals which he captured by pit-falls or in the chase.

These sheep, already domesticated, doubtless supplied man with wool for clothing, and, when unsuccessful in the chase, with meat for food, and ewes' milk was, even at that time, probably an article of diet. As the habits of man became more settled, his principal wealth consisted of flocks and herds, for, in the oldest record, mankind were evidently divided roughly into the two great classes founded upon their occupations, shepherds and agriculturists; and hence we read in the Scriptures that "Abel was a keeper of sheep, but Cain was a tiller of the ground." Even at this early date the care and attention bestowed upon the sheep would improve its useful qualities in a marked degree, and render it increasingly serviceable to man in a variety of ways.

The existence of a race of wild animals, both in Asia, Europe, Africa, and America, which possess a similar affinity to the sheep that a wolf does to a dog, has led some naturalists to suppose that they may have been the original stock from which the domestic sheep has been obtained by cultivation and breeding; but the probability seems to be much higher that these wild animals, along with the domestic sheep, may have had in the remote past a common ancestor, from which they have diverged during the course of ages.

The natural division in the zoological scale to which the sheep belong constitutes the fifth family of the natural order Ruminantia. This family is called the Bovidæ, from the Latin *Bos*, an ox, because it includes within it the various species of animals which we usually term cattle, and also the antelopes, besides goats and sheep. The goats and sheep form the second group of this family, and are easily distinguished from each other by their appearance

as well as by their structural differences. Both the sheep and goats are furnished with horns, which are compressed, usually angulated, rugose, and turned more or less backwards, and sometimes twisted into a close spiral. Except in some of the domesticated varieties, both sexes are furnished with horns, but those of the female are much smaller than the male, whose horns sometimes reach very large dimensions. When in the wild state all these animals associate in flocks, and inhabit the mountainous districts of every quarter of the globe. The goats, as a rule, prefer the highest ground, and are more hardy than the sheep, while the latter prefer to remain in the richer pastures in the bottom of the valleys, or on the plains at the base of the mountain.

The Goats (Capridæ) are distinguished by having the horns simply recurved, and by the total absence of the lachrymal sinuses and glands between the hoofs. The males are always furnished with a beard beneath the chin. The habits of all the goats in all parts of the world are the same. The external covering of the goat consists of long hair, which differs in thickness and length on different parts of the body, and which varies in quality and fineness in different species, and during different periods of the year. The coat is thick and solid, and consists of two different classes of hair; the outer coat being much longer and thicker, while the undergrowth consists of a kind of woolly hair, which has a greater tendency to curl and mat together. Like the sheep, the quality of the hair can be greatly improved by breeding and cultivation, and can be made to grow long, fine, and silky, until it forms a beautiful material for textile fabrics. No cultivation, however, can prevent the growth of the outer hair, as in the case of the sheep, or change the undergrowth of fine hair into true wool.

The Aoudad.—Intermediate between the goat and the sheep is the Aoudad (*Ammotragus tragelaphus*), a remarkable sheep-like creature, which is found in the mountain ranges of North Africa, ranging from Abyssinia to Barbary. It is of a reddish-brown colour, and has a strange-looking appearance, occasioned by a large quantity of long hair which hangs down from the front of the neck and the base of the fore-legs. Like the goat, it has no lachrymal sinuses, but it possesses a gland between the hoof in common with the sheep.

Sheep.—The true sheep (Ovidæ) are distinguished structurally from the goats by the possession of both lachrymal sinuses and glands between the hoofs, which produce a fatty secretion. Their horns are also, unlike the goat, frequently twisted into a spiral. The forehead or outline of the face is convex. There is no lachrymal or respiratory opening under the eye, and the nostrils are lengthened, and terminate without a muzzle. The beard, which is so conspicuous in the goat, is wanting in the sheep. The covering of the body is long and woolly, with an undergrowth of finer wool. In the wild state the longer wool is mixed with hair like that of the goat; but, unlike the goat, by cultivation and domestication this hair can be entirely done away with or bred out, and the whole covering of the skin made to consist of true wool only. Even in its most cultivated state, however, there are occasional hairs of a coarse and solid character appear amongst the wool, especially about the neck and base of the legs, which are often the source of annoyance in the manufacture and dyeing of wool.

Few creatures seems to be capable of greater variety than the sheep, and, in consequence of this and our ignorance of its origin, it is a matter of very great difficulty

to classify the various different forms which it has assumed under different conditions. Some naturalists suppose that there are only three :—

(1) The *Ovis ammon* or argali, which is the wild sheep of Asia and America.

(2) The *Ovis musimon* or moufflon, which is found in Southern Europe and the north of Africa.

(3) The *Ovis aries* or domestic sheep, which abounds in Europe, and notably in England.

The *Ovis montana* or Big Horn, which is found in the Rocky Mountains of America, is considered by this division to be the same as the argali, and is frequently called the American argali.

Other naturalists make a wider division, and regard what under this classification are considered to be sub-varieties as distinct varieties. Professor Archer regards the class Ovis from an industrial point of view, and as having relation only to those sheep which are domesticated or useful to man, as consisting of thirty-two varieties, of which four are inhabitants of Europe, fifteen of Asia, eleven of Africa, and two of America. This classification is as follows :—

I. EUROPE.

1. The Spanish sheep or Merino sheep (*Ovis Hispaniensis*).
2. The common sheep (*Ovis rusticus*).
3. The Cretan sheep (*Ovis strepsiceros*).
4. The Crimean sheep (*Ovis longicaudatus*).

II. ASIA.

1. Hooniah, or black-faced sheep of Tibet.
2. Cago, or tame sheep of Cabul (*Ovis cagia*)
3. Nepal sheep (*Ovis selingia*).
4. Curumbar, or Mysore sheep.

5. Garar, or Indian sheep.
6. Dukhun, or Deccan sheep.
7. Morvant de la Chine, or Chinese sheep.
8. Shaymbliar, or Mysore sheep.
9. Broad-tailed sheep (*Ovis laticaudatus*).
10. Many-horned sheep (*Ovis polyceratus*).
11. The Pucha, or Hindostan Dumba sheep.
12. The Tartary sheep.
13. The Javanese sheep.
14. The Barwall sheep (*Ovis Barual*).
15. Short-tailed sheep of Northern Russia.

III. AFRICA.

1. Smooth-haired sheep (*Ovis Ethiopicus*).
2. African sheep (*Ovis Guinensis*).
3. Guinea sheep (*Ovis ammon Guinensis*).
4. Zeylan sheep.
5. Fezzan sheep.
6. Congo sheep (*Ovis aries Congensis*).
7. Angola sheep (*Ovis aries Angolensis*).
8. Yenu, or Goitred sheep (*Ovis aries steatiniorius*).
9. Madagascar sheep.
10. Bearded sheep of West Africa.
11. Morocco sheep (*Ovis aries Numidiae*).

IV. AMERICA.

1. West Indian sheep found in Jamaica.
2. Brazilian sheep.

Extensive as this classification appears, there is reason to suppose that many of the sub-varieties which are known to exist as the result of the intermixture of these various kinds of sheep, possess characteristics which, if we did not know their origin, would almost entitle them to be considered as separate varieties. It is also probable that

many of these may be the result of intermixture and subsequent variation on account of locality and pasture. This will appear all the more reasonable when it is seen that there are no less than thirty-one sub-varieties known of the common sheep, some of which differ from each other quite as much as many which are regarded as distinct varieties. Some authorities are of opinion that there are only two varieties of sheep, the long and the short-woolled, and that all the others have been obtained by crossing and variation produced by climate and pasturage.

The very wide area over which the domestic sheep is found, the general characteristics which all the varieties possess, and the habits which are so similar, seem to indicate that it was one of the very earliest of all the domesticated animals; and although we can probably never settle the question as to what was the exact character of the original creature from which it was first derived, we can form probably a pretty close approximation by looking at the two wild varieties which are still found in the four quarters of the globe.

The Argali inhabits the mountains and elevated plains of Central Asia, which stretch from the Caucasus, northward and eastward, to Kamtchatka and the ocean. They are usually found in small flocks, pasturing in the higher valleys and mountains during the summer months, and descending into the lower valleys and plains during the winter, so as to avoid the inclemency of the weather and scarcity of food on the higher lands. They are agile and strong, but timid and shy, and in their habits very much resemble the domestic sheep. They are also easily tamed when taken young. Professor Low says: "The argali possesses all the genuine characteristics of the sheep, but is larger, being somewhat less than the size of a stag. It has

enormous horns, measuring more than a foot in circumference at the base, and from 3 to 4 feet in length, triangularly rising from the summit of the head so as nearly to touch at the root, ascending, stretching out laterally, and bending forward at the point. It has a fur of short hair, covering a coat of soft white wool. The colour of the fur externally is brown, becoming brownish-grey in winter. There is a buff-coloured streak along the back, and a large spot of a lighter buff colour on the haunch, surrounding and including the tail. The female differs from the male in being smaller, in having the horns more slender and straight, and in the absence of the disc on the haunch. Both sexes have a shortish tail, whitish eyelashes, and the hair beneath the throat is longer than on the other parts of the body." When the argali is domesticated and removed from its wild habitat, the quantity of hair on the body diminishes and the quantity of wool increases.

The Rocky Mountain Sheep, or argali of the American continent, closely resembles the Asiatic variety, but it is rather larger and stronger. It inhabits all the lofty mountain chains of North America, and moves in large flocks from the mountain fastnesses into the valleys and *vice versa*, with the changing seasons of the year. Its range extends within the temperate zone to the borders of the Arctic circle, and is described by some Spanish writers under the name of the Californian sheep.

The Musmon.—The European and African variety is known as the *Musmon*. In Europe it still abounds in some of the islands of the Greek Archipelago, such as Crete and Cyprus; and its range extends through Corsica and Sardinia into the mountains of Murcia, in Spain, in which country it once abounded. The musmon is smaller than the argali, and although the male has a formidable pair

of horns, nearly 2 feet in length, very thick, and differing from the horns of the argali by turning inward instead of outward at the points, in the female the horns are frequently wanting altogether. The body is covered with a hairy, brownish fur, beneath which is a short, fine, grey-coloured wool, which covers all the body. When the musmon is captured and kept in a state of confinement it has all the habits of the domestic sheep, with which it is capable of breeding, and the offspring is also fruitful. Whether or not our domestic sheep is derived from any of these wild sheeplike creatures, there is no doubt but that its domestication first occurred in Asia, and from thence was introduced into Europe with advancing civilisation, and its introduction was always accompanied by a great increase in the comfort and wealth of the owners. In Europe it appears first to have been brought into Greece, where, as is recorded by its early poets and historians, it was highly prized. Its introduction is probably enshrined in the legend of the expedition of the Argonauts in search of the golden fleece. After the foundation of Rome it was probably brought into Italy by the Grecian colonists, and from thence it spread with the advance of Roman civilisation into Spain, Gaul, and Britain.

Although the wild sheep possess considerable interest, as exhibiting the probable original condition of the creature, undoubtedly our greatest interest lies in the domestic varieties, and in the sub-varieties which have been produced artificially by the mixture of races under cultivation. It is in these classes that we find the wool-bearing qualities of the sheep brought into the greatest perfection, and therefore rendered of the greatest use in the textile arts. Thus, while all the wild forms of sheep exhibit a great similarity in the structure of the hair, and

in the mixture of true wool along with it, it is only when we come to the most thoroughly domesticated and cultured sheep that we find the entire disappearance of the coarse hair, and its replacement by a pure and perfect wool,—a wool in which all the best and most desirable qualities as a textile raw material are found blended together. Nothing can show this difference more strikingly than a comparison between the coarse, hairy covering of the argali or the musmon and one of the fine Saxony Merino, or one of the Australian Botany sheep with its silk-like pure wool. As we have already stated, the sheep is found in every part of the globe; and in looking shortly at the principal varieties, especially of the domestic sheep, it will be better to adhere to the geographical divisions, beginning with the sheep of—

I. EUROPE,

and taking as a starting-point those which are found in our own islands.

SHEEP OF THE UNITED KINGDOM

In reviewing the various classes of domestic sheep, it seems best that we should commence with those which exist in the United Kingdom; and all the more so because until a comparatively recent date these English wools formed the staple article of consumption in the Bradford trade. As we might naturally expect, the great variety of mountain and plain, valley and marsh, as well as the detached islands off the coast of Scotland, exhibit a great variety in the characteristics of the sheep, and it is very difficult to make any exact classification of them all. The crossing of the various breeds has introduced many sub-varieties, and their

character has also been much changed by the method of feeding adopted, by which it has been intended to improve the flesh as an article of diet as well as to improve the wool. The former of these considerations has always been a great point with English farmers, because the large manufacturing centres have formed one of the best markets in the world for butchers' meat, and hence, in many cases, there has been a willing sacrifice of those properties which might have tended to increase the quality of the wool in the endeavour to produce large and heavy sheep, and those which would fatten with the greatest rapidity,—the wool-bearing qualities being looked upon as almost subordinate. It will of course be quite impossible to give more than a very cursory account of the various breeds of sheep. The very great variety also which are found even within the limits of the United Kingdom presents another difficulty, and renders it quite impossible to do more than merely glance at the typical ones. The easy means of communication with different parts of the kingdom, and the desire for improvement, which has led to a large transference of stock from one part to another, have rendered classification either in regard to race or distribution extremely difficult. Several methods of classification have been suggested, but the author has adopted that suggested by Prof. Low in his work on the Breeds of Sheep and Cattle, and extended by Mr. W. C. Spooner, in monograph of the History, Structure, etc., of the Sheep,[1] to which he must refer those who wish for further information than is given here. Also to an excellent work by Professor Wrightson.[2]

[1] *The Sheep*, W. C. Spooner, M.R.V.C., Crosby, Lockwood & Co., 1878.

[2] *Sheep*, John Wrightson, M.R.A.C., Vinton & Co., London, 1905.

We may, therefore, consider a classification of the sheep of the United Kingdom to be generally made as follows :—

I. The wilder and most primitive breeds.
II. The forest and mountain breeds.
III. The ancient upland breeds.
IV. The long-woolled breeds.

I. As we might naturally expect, the wilder and more primitive breeds of sheep are found in the most remote parts of the kingdom, where communication is difficult, and where improvements are likely to be most slowly adopted.

Highland Sheep.—In the extreme north of Scotland, in the Orkney and Shetland Islands, and the Hebrides, a race of sheep exists which seems to be allied to the Norwegian and Scandinavian race found on the opposite coast of Europe, whence it was probably derived. They are extremely hardy creatures, and more like a goat than a sheep in their appearance and habits. They have a short tail, and this distinguishing feature has earned their name, —"short-tailed sheep,"—by which they are known. In some of the islands they have been mixed in breed; but, when pure, they are of various colours—black, brown, grey, white, and spotted. The fleece consists of a mixture of hair and wool. The wool does not increase in length from year to year, but falls off each year on the approach of summer, leaving the hair alone as a covering during the hot season. The fleece is not therefore shorn, but plucked off the sheep, and is fine and soft; but, as it contains only few serrations, is not well adapted for felting, but can be spun into yarn, from which coarse garments are made. Attempts have been made to improve this breed, but the probability is that it will be superseded by some of the hardier varieties of sheep already in existence, such as the

Cheviot. When the wool is full-grown it is very long, as will be seen in Fig. 30.

Welsh Sheep.—In the mountains of Wales there are, according to Prof. Low, two different varieties of sheep, which are natural to the locality. One, which he terms the sheep of the higher mountains, and the other the soft-

FIG. 30.—Black-faced Mountain Ram.

woolled sheep. The higher mountain sheep is various coloured, like the Highland sheep, and goat-like in appearance; but it has a long tail and a ridge of hair on the back, with the throat and dewlap white, and the face and legs always black. They are very wild and active, and always prefer the highest pasture-ground. This mountain sheep is probably the original stock of the

Radnor sheep, which is larger and heavier, with a better fleece, but still retaining the black face and legs. The soft-woolled sheep are the distinguishing breed of Wales. They are small and active, with a white face, and furnish the wool from which the famous Welsh flannel is made. The flesh is firm and sweet, and much in request as an article of diet. The fleece always contains a certain

FIG. 31.—Welsh Mountain Ram.

mixture of hair, although less than in most mountain sheep, and this is particularly noticeable on the throat. This sheep is illustrated in Fig. 31. The richer and lower lands in Wales are now stocked with Cotswold, Shropshire, Oxford Down, and Leicester sheep, or with cross-bred sheep derived from these varieties.

Irish Sheep.—The sheep of Ireland, like those of Wales and England, are of two distinct varieties,—those

which inhabit the mountains, and those which are found in the valleys. The mountain sheep are found principally in the counties of Wicklow and Kerry. The former are the most valuable, and closely resemble the Welsh mountain sheep. They are wild little animals, without horns, and with white faces and legs. On the higher pasturages the wool is coarse and much mixed with hair; but when removed to better grazing-ground the wool becomes softer and longer, and the hair less, although it never entirely disappears, but is confined more particularly to the ridge of the back. When crossed with a better breed, such as the Southdown, considerable improvement has been effected, and as the lambs feed quickly, and are therefore soon ready for market, they are much esteemed by the farmers. The Kerry sheep are larger than the Wicklow breed, but they lack many of the advantages which the latter possess, and neither as wool-bearers nor for food are they so suitable at the same early age. The mutton, however, is good.

The sheep which are found in the plains of Ireland are much larger than the mountain races. They are large, long-woolled animals, resembling the native sheep of the midland counties of England. Within late years very great improvements have been introduced into them by crossing with other and more cultivated races imported from England. This has been abundantly seen in the improved quality and character of the wool which has been received in the English market. The Roscommon sheep closely resembles the Leicester breed with which it has been crossed.

II. In looking at the breeds of mountain sheep which inhabit England and Scotland, it becomes a matter of considerable difficulty to exactly distinguish between them, because they range over the whole of the kingdom from the south to the extreme north, along the mountain range

and its offshoots which forms the backbone of England. In the south we have the *Exmoor and Dartmoor* sheep in Devonshire and Cornwall; the *black-faced heath* or moor sheep in the higher ranges of Derbyshire, Lancashire, Yorkshire, Cumberland, and Westmoreland, until they meet with the *Cheviot*, which inhabits the mountains in

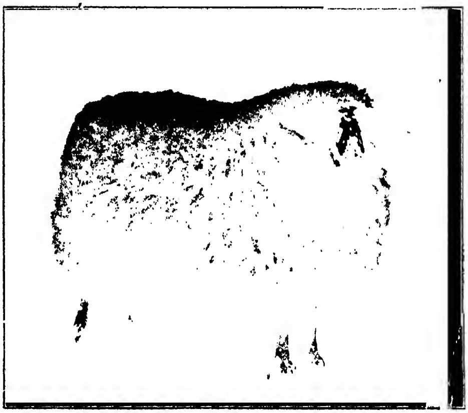


FIG. 32.—Lonk Ram.

Northumberland and the south of Scotland. The *Herdwicks* are found in Cumberland and Westmoreland; and the *Penistone* sheep inhabits the hills of Yorkshire, Lancashire, and Derbyshire, in the immediate neighbourhood of the town of Penistone. There is also a cross breed with the black-faced sheep, which is larger than the Herdwick sheep, and is called the Lonk, which is found in Cumberland, Westmoreland, Durham, and on the hill ranges of York-

re and Lancashire, which is believed to be its original home. This sheep is represented in Fig. 32, and is considered by some as the best adapted for the hilly districts.

The Exmoor and Dartmoor Sheep are small, with white faces and legs, and are well adapted by their hardy character for the poverty of pasture which is found in the

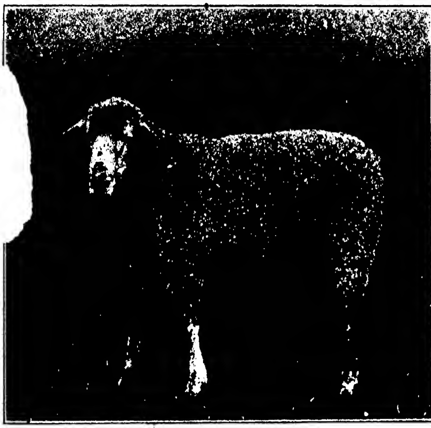


FIG. 33.—Dartmoor Ram.

higher lands of Cornwall and Devon. The Exmoor sheep are the smaller of the two, and the males have a slight beard under the chin not unlike a goat. They are wild and restless, and covered with soft wool. When crossed with the Leicester they are much improved in size, and when fattened the mutton finds a ready sale on account of its excellent quality. Fig. 33 shows a characteristic Dartmoor long-woolled ram.

The Black-faced Heath Sheep is larger and more robust than the Welsh mountain sheep, and in some of its characteristics resembles the sheep of Persia and Wallachia. Both the male and female have horns, which are very large, and spirally twisted in the male, but sometimes entirely wanting in the female. The limbs are lengthy and muscular, and the form is robust. The face and legs are black, the fleece being coarse and shaggy, and while the colour is sometimes black or grey there is no tendency to brown or russet, and in this respect these sheep differ from all the other mountain breeds. The wool is of a medium length, and the fleece when washed weighs about 3 to 4 lbs., and is never heavy on the body. The character of the wool also is such that it can only be used for the coarser class of yarns, such as those employed in the manufacture of carpets. The most serious defect, however, is the frequent occurrence of "kemps" in the wool. These are wiry hairs without any serrations on them, and are entirely destitute of the felting properties necessary to give them a good spinning quality; and what is worse, they resist all reagents in dyeing, as they seem to possess no open cells into which the dye can penetrate. These sheep do not appear to amalgamate readily with other races; but by cultivation and selection of suitable sire and dam considerable improvements have been made in their properties. Crossed with Cheviot, Leicester, and Southdowns, several sub-varieties have been produced which are a marked improvement on the old stock, both for food and wool-bearing qualities. The great hardiness of the race, and its fitness for enduring the hardships and exposure necessary to the heath-covered hills in winter,—the scanty food upon which it can live, and the little attention which it requires, render it one of the most extensively cultivated

of the English sheep. It even supplants the Cheviots on the higher grounds in the border counties on account of its great hardiness.

The Cheviot Sheep is one of the most valuable breeds in the kingdom, and takes the place of the black-faced heath sheep in the mountains in the Lowlands of Scotland from which it derives its name. It has extended from

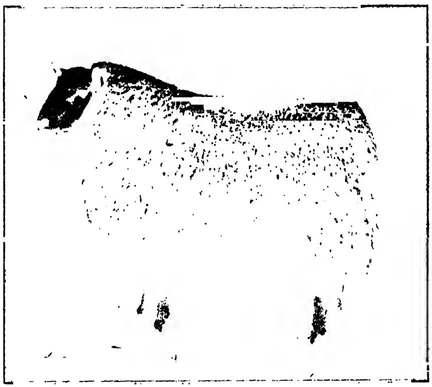


FIG. 34.—Cheviot Ram.

there southward into the hilly districts in the border counties of England, and northwards into the Highlands, where it has in many places supplanted the native mountain sheep. It is a very hardy creature and thrives well on very poor pasture, surviving with comparative ease the very severe weather to which it is subjected in the winters, which render the Cheviot hills quite unsuited for other breeds. They are thus described: "They have white

faces and legs, open countenances, lively eyes, and are without horns. The ears are large and somewhat singular, and there is great space between the ears and eyes. The carcass is long; the back straight; the shoulders rather light; the ribs circular, and the quarters good. The legs are small in the bone and covered with wool, as well as all the body, with the exception of the face." Fig. 34 gives a very good illustration of this valuable sheep, which may be taken as the type of the mountain breeds. Although the Cheviot is a mountain sheep, it is less active and more docile than many other mountain breeds, and has been much improved in certain districts by crossing with other long-woolled sheep, as well as with Down sheep. The wool is usually fine in quality, and grows thick upon the body, thus forming a good protection against the weather. The fleece usually weighs from 3 to 4 lbs. Although since the introduction of Botany wool it is not used so much as formerly in the production of cloth, it is extensively used in the manufacture of Tweeds and Cheviots, as its name implies. The crossing with other sheep, especially the Leicester, has materially improved the character of the wool, but it has tended to detract from the hardy character of the race, and hence throughout a large part of the districts where it is found it flourishes best in its purest state. These improved sheep are called Border Leicesters or Leicester Cheviots.

The Herdwick Sheep are found only in the mountains of Cumberland and Westmoreland, and are, like the Cheviots, able to live on coarse fare and endure great exposure without injury. They are without horns, and the wool is coarse and open, the fleece weighing about 3 to 4 lbs. They fatten slowly, but when matured the quality of the mutton is excellent. Unlike most mountain

sheep, they remain attached to a particular spot, and seldom stray far away from it. Fig. 35 shows this sheep. Tradition says that these sheep were improved by crossing with some Spanish sheep which were saved from the wreck of one of the vessels of the Spanish Armada.

The Penistone Sheep is distinguished from all the

FIG. 35.—Herdwick Ram.

mountain sheep of this country by its extreme coarseness of form, especially at the extremities, and the large, muscular, and bony character of its long tail. The weight of the fleece is from 4 to 5 lbs., and the wool is of a silky appearance and medium length, but it is harsh and wiry, and only fitted for the coarser class of fabrics. The males have large horns, lying close to the head and projecting forward. The limbs are bony; the feet large; the

shoulders heavy, and the sides fat. They feed well, and the mutton is of first-rate quality.

III. **The Ancient Upland Breed** of sheep comprise, with the sub-varieties produced by crossing, the whole of the most valuable wool-bearing sheep of the United Kingdom, as regards the fineness and quality of the fleece. They are the inhabitants of the south, east, and west of England, and the Downs of the southern counties, and possess many of the most valuable qualities which are to be desired in a sheep. The distinctive classes are usually named from the districts in which they are found; but they are all more or less intermixed with other breeds, and into no class of sheep have greater improvements been introduced than into these by judicious crossing. The Southdown, which is included in this class, is, however, one of the purest and most unmixed breeds in the kingdom, and is the type of the short fine-woolled sheep, just as the Leicester is of the deep-grown woolled sheep.

The Old Norfolk Sheep were formerly found very extensively in the higher lands of Norfolk, Cambridgeshire, and Suffolk; but latterly they have been to a great extent replaced either by a cross with the Southdown or by the Southdown itself. They somewhat resemble the black-faced heath sheep, but have longer bodies and much finer wool. They have black faces, with horns in both sexes, long limbs, and are very active in their habits. The wool is mostly used for carding purposes, and made into livery-cloths, either alone or mixed with finer wools.

The Dorset Sheep is probably the best of all the old horned sheep of the country, and has been preserved pure from a very remote period. They are strong, hardy, active sheep, much wilder and less docile than Southdowns, which they exceed in size. They have longer legs

than the Southdown, white faces and legs, and horns of moderate length in both sexes. The wool is moderately long,—longer than the Southdown,—scarcely so pure in quality, but brighter in appearance and almost entirely free from grey, and the weight of the fleece is from 3½ to 4 lbs. The great value of this sheep, however, consists in its prolificness, since they rear a larger number of lambs than any other sheep, and at an earlier period. It is from this source that the supply of Christmas lamb in the London market is derived. This is a matter of considerable importance, because, since the great decline in the price of English wool, the farmer has to pay special attention to the rearing of sheep and lambs for the meat market.

The Somerset Sheep is a variety of the Dorset sheep, but more of the Leicester character, and differing from the Dorset in having a pink nose in place of black or white. The wool also is longer and heavier.

The Portland Sheep is also a variety of the Dorset, and is raised on the island of the same name. They have horns, and white faces and legs. The wool is coarser than on the Dorset sheep, and the fleece very light, but the flesh is delicate and excellent, and they are principally reared for the London market, where they command a good price.

The Old Wiltshire Sheep are nearly extinct, having been almost entirely replaced by other and more profitable breeds, or crossed with Leicesters, and so merged into half-breed sheep. They are large in size, and horned in both sexes, with Roman noses, and white legs and faces. They carry very little wool, the fleece only weighing about 2½ lbs., and they fatten slowly.

The Old Hampshire and the **Old Berkshire sheep**

somewhat resembled the old Wiltshire, and both have now become practically extinct, having been replaced by Southdown and other more cultivated and useful sheep, though at one time they abounded in large numbers in the counties which are associated with their names.

The Hampshire Down Sheep is now found generally in the northern division of the county, and extending into Berkshire and Wiltshire. The precise origin of this variety is difficult to discover; but it probably originated in the native sheep which existed there before the time of the Romans, and its present characteristics have been obtained by judicious crossing with more improved sheep. This sheep is larger than the Southdown, with longer legs and coarser bones, but the quality and weight of wool is somewhat similar. This sheep is represented in Fig. 36.

The Improved Hampshire Sheep are examples of successful crossing, and a proof of what can be done by the male parent in the course of a few generations in changing the character of the original, and producing a breed which is more valuable in every way than either of the sources from whence it was derived. They unite the qualities of the original Hampshire with the Sussex and Cotswold sheep, and thus produce a first-class sheep, both in size, appearance, and wool-bearing properties.

The Southdown, or Sussex Breed, is a typical sheep. It is unquestionably one of the purest and most valuable sheep in the kingdom, and its descent can be traced to a period antecedent to the Norman Conquest. It stands first amongst all the short-woolled English sheep, not only on account of the fineness and quality of the wool, but also of its fattening and meat-giving character. These sheep have reached their present perfection by constant and unremitting attention to the purity of the original breed,

and the careful weeding out of any sheep which showed any retrograde characteristics. The utmost attention has also been paid to the feeding and rearing of them, and this has not only tended to the increase of their numbers but to the improvement both of the flesh and wool in every respect. Latterly they have been crossed to some extent with heavier-woolled sheep, and this, along with improved

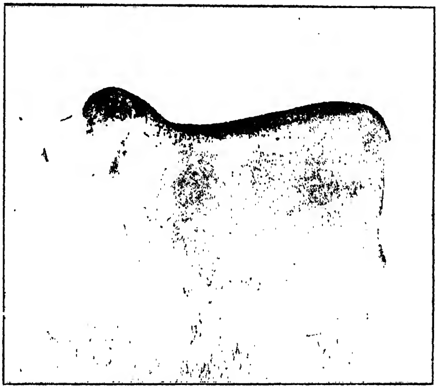


FIG. 36.—Hampshire Down Ram.

farming, has tended to strengthen the character of the fibre. Nothing can show the sterling qualities of this breed better than the fact that, with the large influx of foreign fine wool into this country, the Southdowns have not only maintained their numbers, but actually increased, although the wool is now principally used for combing purposes, whereas at one time it was exclusively used for carding. They have also very much extended in the area which they

cover, and have, in many instances, supplanted entirely the native sheep in those localities which are suited for their habits and constitution. This improved sheep has thus been described: "The head is small and hornless, and the face brown-grey in colour, and neither too short nor too long. The lips are thin, and the space between the eyes and nose narrow. The under jaw is fine and thin; while the ears are tolerably wide and well covered with wool. The forehead also and the space between the ears is covered with wool. The eyes are full and bright, but not prominent, and the orbit of the eye not too projecting. The neck is of medium length; thin towards the head, but enlarging towards the shoulders, where it is broad and high, but straight in its whole course above and below. The breast is wide, deep, and projecting forwards between the fore-legs, indicating a good constitution and a disposition to thrive. Corresponding with this, the shoulders should be on a level with the back, and not too wide above; they should bow outwards from the top to the breast, indicating a springing rib beneath, and leaving room for it. The ribs coming out horizontally from the spine and extending far backwards, and the last rib projecting more than the others. The back flat from the shoulders to the setting on of the tail. The loin broad and flat, and the rump long and broad. The tail set on high, and nearly on a level with the spine. The hips wide, with the space between them and the last rib on either side as narrow as possible, while the ribs present a circular form like a barrel. The belly is straight as the back. The legs neither too long nor too short. The fore-legs straight from the shoulder to the foot, not bending inwards at the knee, and standing far apart both before and behind. The hocks having a direction rather outwards, and the twist or

the meeting of the thighs behind being particularly full. The bones fine, yet having no appearance of weakness, and the legs of a dark colour. The belly well protected with wool, and the wool coming down, both before and behind, to the knee and to the hock. The wool short, close, curled, and fine, and free from spiry projecting fibres."[1]

FIG. 37.—Southdown Ram.

Such is a description of this favourite sheep, which has extended itself into all parts of England, Scotland, and Ireland, and a representation of which is given in Fig. 37. It has almost supplanted the native breeds in Norfolk, Cambridgeshire, and many other counties; and in Hampshire, Wiltshire, and Dorset it has been extensively crossed with the native breeds. The breed is well adapted for

[1] *The Sheep*, W. C. Spooner, M.R.V.C., p. 41.

hilly pastures wherever the chalk prevails; but as it has not the hardy character of many of the mountain races, it cannot replace the black-faced heath sheep, or the Cheviots, or the mountain sheep of Wales and Ireland. The superior quality of the mutton, and the due proportion of lean and fat in the carcass, render it a greater favourite than even the Leicester sheep in the London market, and for this purpose, therefore, it has been crossed with Shropshire rams so as to produce a sheep partaking of the character of both parents, and having earlier maturity and superior feeding qualities to the pure Southdown.

The Shropshire Speckle-faced Sheep is a cross-breed between the original horned sheep and the Southdown. The original sheep was probably the Morfe Common sheep, which is still found near Bridgenorth, and which produces a superior quality of wool; but as it has been crossed with other breeds, particularly the long-woolled Leicester and Cotswold sheep, as well as the Southdown, a corresponding variation from the original has been produced, and to-day there is no sheep which has been more improved in every respect. It was the first of the short-woolled sheep in this country which are not Southdown. It is now very extensively cultivated, and it is said to be the most profitable sheep to the producer, the butcher, and the consumer. A great admirer and breeder of this sheep once remarked, "It is a farmer's sheep, a rent-paying sheep, a tenant's sheep. It is a money-making, wool-producing, mutton-carrying sheep. It is a bank, a save-all, a frugal-living and quick-fattening, hardy sheep." Fig. 38 gives a good illustration of it.

The Ryeland Sheep has been preserved from a remote time in the County of Hereford, and from thence has extended itself into Shropshire, Monmouthshire,

Gloucester, and Warwickshire, where it has received various names. These sheep are small, without horns, and distinguished for the great fineness of the wool, which is superior for carding purposes to all others which are produced in England, the Merino alone excepted. The introduction of fine foreign wool into the country has much interfered with the cultivation of this sheep, because any

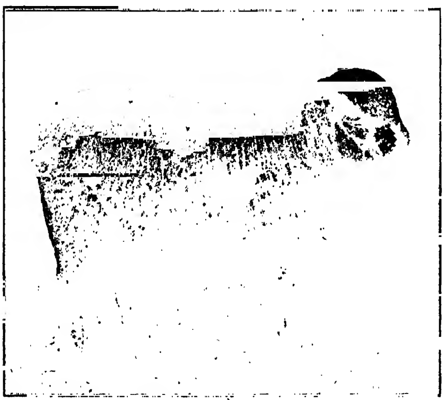


FIG. 38.—Shropshire Ram.

attempts to improve its character so as to compete with this have resulted either in the deterioration of the sheep for food purposes, or else its deterioration as a wool-bearer if the former character was preserved. The cross with the Leicester has been most successful, but the quality of the fleece has been entirely changed and rendered fit for combing purposes.

IV. **The Long-Woolled Breed of Sheep** are

diametrically opposite to those of which we have last been speaking. They are distinguished for their great size and the great length and weight of the fleece, and in this respect the most improved breeds of England are without any rival in the world. They are properly the natives of the rich marshy pastures of the west and midland counties of England, from whence, with the improvements in agriculture and the demand for long wool, they have spread into all parts of the country. Even in those counties where the short-woolled sheep abound there has been extensive crossing with the Leicester and allied breeds. Wherever suited to the district they have been found more profitable than the short-woolled sheep, not only on account of the greater weight of the wool which they produced, but also in one particular variety on account of their earlier maturity and greater aptitude for fattening. While many of the upland and mountain breeds of sheep have been preserved pure, the ancient long-woolled sheep have, in almost all cases, undergone modification by crossing so as to secure certain improvements. It is a matter of considerable difficulty to trace the original stock from whence the various breeds have been derived. Prof. Low thinks that there were originally two distinct varieties, one of which belonged to the marshes and fens, and of which the Lincoln and Romney Marsh sheep are now the representatives; the other inhabiting the inland plains, and which are now represented by the Teeswater, Leicester, and other varieties. The wool from these sheep has a peculiar interest for those engaged in the Bradford trade, because it was from the use of these wools that the worsted trade, as distinguished from the woollen trade, originally took its rise, and they formed the staple articles of consumption before the demand for soft goods, and the

introduction of such large quantities of Botany and other fine wools into the district, and they still hold their own in the manufacture of the warps for the all-worsted goods.

The Lincoln Sheep stands at the head of the long-woolled sheep, not only on account of the length of the

Fig. 39.—Lincoln Ram.

wool, but also of the weight of the fleece, which averages from 8 to 9 lbs. weight. The old pure Lincoln breed is now almost extinct, because it has been found that by crossing with the New Leicester a breed of sheep has been obtained which we may term the New Lincoln, and which possesses a greater aptitude to fatten, an earlier maturity, as well as an improved form. A larger number

of sheep can also be kept on the same extent of land. In consequence of this, although the size of the sheep has been slightly reduced, it is the best wool-producer as well as the largest sheep in Europe. It is of a large and coarse form. The fleece often weighs as much as 10 or even 12 lbs., and hangs down all round, almost touching the ground. When spread out on the sorting-board some of the largest fleeces seem almost too large to have ever been upon a single sheep's back, having even reached the enormous weight of 24 lbs. We must remember, however, that some of the largest sheep reach from 350 to 360 lbs. weight when slaughtered. The length of the wool on the longest part of the fleece also sometimes reaches an incredible length. The author retained for some time a lock from a fleece which he sorted which measured over 36 inches in length. The wool, although bright and silky, is coarse in texture; but within recent years their introduction into Australia and New Zealand for crossing purposes has produced a class of sheep which have a beautifully pure and silky hair along with a great length. These sheep are principally found in the fen district of Lincolnshire, but from thence they have extended into Norfolk, Cambridgeshire, and the adjoining counties, and crossed with the Leicester into every district in the United Kingdom where suited for the growth of long-woolled sheep. Fig. 39 gives a good illustration of the celebrated sheep.

The Romney Marsh Sheep is another breed of long-woolled sheep inhabiting from time immemorial the fen district on the southern coast of Kent from which it derives its name. The native breed of this district were large and coarse animals, rather smaller than the Lincoln, but since they have been crossed with the New Leicester they have much improved in every point, and now are

represented by a large handsome sheep which yields moderately fine and deep-grown wool. This is represented in Fig. 40.

The Wensleydale Sheep is the modern form of the Teeswater Sheep, which originated in a large and ancient breed of sheep in the valley of the Tees, that separates the counties of York and Durham. It was a

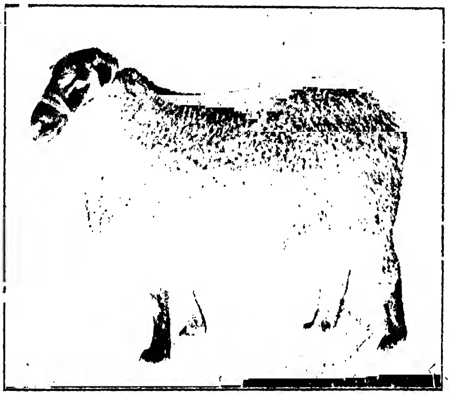


FIG. 40.—Kent or Romney Marsh Ram.

large, tall sheep, of very coarse form, with large head, rounded haunches, and long limbs. The wool was very long, but rather scanty, which, since crossing with the Leicester, has much improved—so much so that the cross has entirely supplanted the original. The wool is very bright and curly, and the locks are very free and distinct. The quality of the mutton is very good; and the thrifty habits and hardy constitution of this breed render it a

great favourite in the dales of the North Riding of Yorkshire.

The Warwickshire Sheep was another variety of long-woolled sheep, rather smaller in size than the Teeswater, with heavy bony frame, long thick legs, and great splay feet; but this animal has almost if not entirely become extinct, having been replaced by more improved animals such as the New Leicester.

The Bampton Nott is found in the fertile valleys of Devonshire and Somersetshire, round the village of Bampton, from which it derives its name. Crossed with the Leicester it has produced a valuable breed of sheep, in which the original defects of the native breed have disappeared. A smaller variety called Southam Notts also exists, and these two classes of sheep, crossed with the Leicester, represent the long-woolled sheep of Devonshire and the southern part of Hampshire.

The Devonshire Southam Sheep originated in the southern part of that county in the neighbourhood of the Vale of Honiton, and up to the borders of Dartmoor. From thence they have extended into Cornwall, where they are extensively bred, and have been much improved by crossing with Leicesters. They somewhat resemble the Romney Marsh sheep, but with brown faces and legs. Crossing with Leicesters has removed this colour as well as materially improved them in every other respect, so that they fatten earlier, and a finer and more silky fleece is obtained. The quality is moderately fine and the staple long. The fleece is about 9 lbs. weight.

The Cotswold Sheep, seen in Fig. 41, derive their name from the hills of the same name in Gloucestershire, where they originated, or at any rate have existed for a period beyond authentic history. They are of large size,

without horns, and with a long and abundant fleece. They are principally found in the valley of the Severn and on the surrounding hills. The wool from these sheep has long been celebrated for its length, and in consequence of this property a few were exported to Spain in the reign of Edward IV., where they were much prized and increased

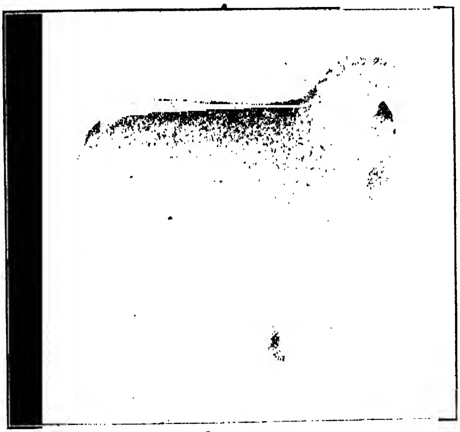


Fig. 41.—Cotswold Ram.

in numbers. Some writers have supposed that they were the originators of the Spanish Merino sheep, but it is probable that they were crossed with already existing Merinos to the advantage of both. The introduction of Leicester sheep into the Cotswold district has greatly improved the old native breed, and the new Cotswolds have a decided advantage over the old on account of the greater hardihood as compared with the pure Leicester

and the deeper grown nature of the wool than in the original stock. The wool, when washed, is of a good colour, and averages from 6 to 8 inches in length, and the fleece weighs from 7 to 8 lbs. The Cotswolds have also been crossed with the Hampshire Down sheep, and produced what is known as the New Oxford sheep.

The New Oxford Sheep originated about the year 1830, when Mr. Twynham crossed a Hampshire Down ewe with a cross between the New Leicester and Old Cotswold. The resulting sheep approximated to the Cotswold in the wool and the Leicester in the carcass, while it much exceeded the parent in size and hardihood. The fleece weighs from 8 to 9 lbs., with a firmer and finer staple than the Cotswold wool, and yet retaining the full length.

The Leicester Sheep, or, as it is now called in its improved condition, the Dishley or New Leicester, is perhaps the most celebrated of all the long-woolled sheep, not even excepting the New Lincoln. In figure, hardihood, and quality, both for wool and mutton, it is almost without a rival, and has been used perhaps more extensively than any other to cross the native breeds of long-woolled sheep in other districts with a view to improve them. It originated with a Mr. Bakewell, who obtained it by a judicious crossing with various long-woolled sheep that he had selected with the best specimens of the Old Leicester breed, which it has now almost replaced. It is now preserved pure as a breed, and while there is no long-woolled sheep which has been crossed with it which has not improved, it has never itself received any further additional advantage by crossing with them. It occupies the same position in regard to the long-woolled sheep that the South Down does amongst the short-woolled.

The following is a description of this typical sheep, which may be compared with the illustration given in Fig. 42:—"The head should be hornless, long, small, and tapering towards the muzzle, and projecting horizontally forwards. The eyes prominent and with a quiet expression. The ears thin, rather long, and directed backwards. The neck full and broad at its base where

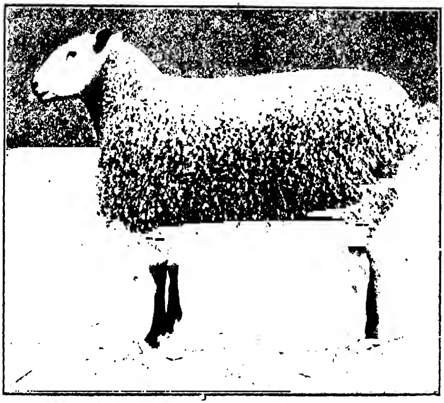


FIG. 42.—Leicester Ram.

it proceeds from the chest, but gradually tapering towards the head, and being particularly fine at the junction of the head and neck, the neck seeming to project straight from the chest, so that there is, with the slightest possible deviation, one continued horizontal line from the rump to the poll. The breast should be broad and full; the shoulders also broad and round, and no uneven or angular formation where the shoulders join either the neck or

the back; particularly no rising of the withers, or hollow behind the situation of these bones. The arm fleshy through its full extent, and even down to the knee; the bones of the leg small, standing wide apart, with no looseness of skin about them, and comparatively bare of wool. The chest and barrel at once deep and round,

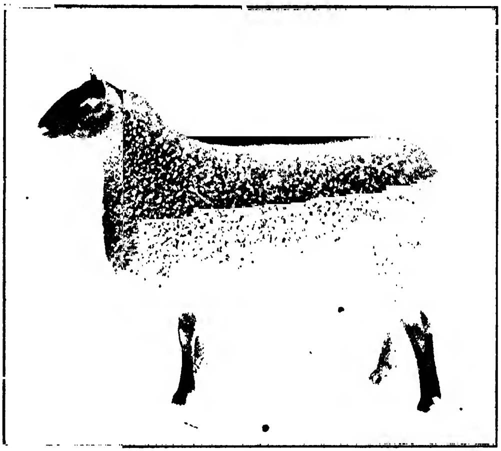


FIG. 43.—Border Leicester.

the ribs forming a considerable arch with the spine, so as in some cases, and specially when the animal is in good condition, to make the apparent width of the chest even greater than the depth. The barrel ribbed well home, with no irregularity of line on the back or belly, but on the sides the carcass diminishing gradually in width towards the rump. The quarters long and full, and as

with the fore legs, the muscles extending down to the hock. The thighs also wide and full, the legs of moderate length. The skin is thin, but soft and elastic, and with a good quantity of white wool, not so long as in some breeds but considerably finer."

Border Leicesters, seen in Fig. 43, are found on both the English and Scotch side of the border, and may be said to form the mainstay of Border Counties farming. They rival in excellency the original Dishley Leicesters from which they were derived, and crossed with Cheviots and black-faced mountain sheep they have earned a reputation which is second to none in the market.

In addition to its unrivalled qualities as a wool producer, the New Leicester has a greater dead weight when slaughtered compared with the live weight than any other sheep, while the flesh and fat are accumulated more externally, and acquired in the greatest degree in the most profitable places and the least in the coarse points.

Showing the importance of sheep-farming in the United Kingdom, it may be noted that the number of sheep returned by the Board of Agriculture was in 1907 as follows:—

England	15,098,928
Scotland	7,313,155
Ireland	3,815,995
Wales	3,703,372
Isle of Man and Channel Islands	79,769
Total . .	30,011,219

CHAPTER VII

CLASSIFICATION AND DESCRIPTION OF FOREIGN SHEEP

DIFFICULT as the task is to describe and arrange all the different breeds of sheep which are found within the United Kingdom, it becomes more difficult when we have to classify those which are found scattered over the four quarters of the globe. Many of the breeds have only a local celebrity, and only small quantities of the wool are received into the English market. The increase of international communications, however, has within the last few years greatly facilitated the transport of wool, and the great demand for new makes of textile fabrics has stimulated the introduction of new fibres, so that large quantities are now received from countries where but a few years ago the export of wool was unknown. Of many of these fibres it is extremely difficult to say which class of sheep has supplied them, as they are principally known as wools named after the port whence they are shipped, and are often mixtures from several varieties of sheep. There are, however, scattered through all the more civilised countries of the world various breeds of sheep which have distinctive characteristics, and these we shall briefly describe, commencing with those which are found on the Continent

of Europe and in the British Colonies, on account of their great importance in this and other markets.

European Sheep

The first amongst all the European sheep, both on account of its intrinsic merits, and also of the close relation which it bears to some of the English and Colonial sheep, stands the *Spanish Merino* breed.

Merino Sheep.—The wool of Spain has always been celebrated from the very earliest times, and during the period of the Roman Empire was justly considered to excel, both in quality and staple, all other known wools. During the Middle Ages and the Saracen occupation of Spain the woollen manufactures of that country were renowned throughout all Europe, and the Italian artisans received their finest wool from that country. With the expulsion of the Moors from Spain the manufactures fell into a state of decay, from which they have not yet recovered, and the introduction of the Spanish Merino sheep into Saxony and Australia and other of our Colonies has deprived her of the monopoly which she once held of this fine breed.

There has probably existed from the earliest times in Spain two different varieties of sheep which corresponded to our long- and short-woolled sheep, and which were further distinguished by their habits, each of them having representatives amongst the stationary and migratory classes; the stationary confining themselves to one district all the year round, while the migratory seek a different pasture at different seasons. The stationary sheep consist of two different breeds and a third or intermediate one.

The Chunah is a larger, taller, and heavier sheep than the Merino, with a smaller head, which is devoid of wool. The staple is about 8 inches long, and much coarser than the Merino, and possessing hardly any curve. It was probably to improve this breed that the Cotswold sheep were imported into Spain from England in 1464, and the descendants of this mixed breed may still be traced.

The Stationary Merinos are chiefly found in the pastures scattered amongst the Guadarrama mountains, the Somo Sierra ranges, and the whole country of Segovia, and hence are sometimes called Segovia Merinos. They produce fine, beautiful wool, but have not the same reputation as the Migratory Merinos, which are so justly celebrated.

The Migratory Merinos, or, as they are called in Spain, *Transhumantes*, are the most celebrated sheep in the world, and excel all others in the fineness of the quality of the wool. They are small in size, with flat sides, narrow chests, and long legs. The first impression made by their appearance is not often favourable, the wool lying closer and thicker over the body than in most other breeds of sheep, and being abundant in yolk, which is an oily, fatty, secretion mixed with the wool, is covered with a dirty crust, often full of cracks. The legs are long, yet small in bone; the breast and the back are narrow; the fore-shoulders and bosoms are heavy; and too much of their weight is carried on the coarser parts. The horns of the male are comparatively large, curved, and with more or less of a spiral form. The head is large, but the forehead rather low. A few of the females are horned, but as a rule are not. Both male and female have a peculiar coarse and unsightly growth of hair on the forehead and cheeks, which is cut away before the shearing

time. The other part of the face has a pleasing and characteristic velvety appearance. Under the throat there is a singular looseness of skin, which gives a remarkable appearance of throatiness, or hollowness in the neck, and the wool is grown in large folded pleats over the neck and all parts of the body. The fleece when pressed upon is hard and unyielding. This arises from the thickness with which it grows upon the pelt, and the abundance of the yolk, which detains all the dirt and gravel which falls upon it. The wool, however, when examined, exceeds in fineness and in the number of curves and serrations which it presents that of any other sheep in the world. The average weight of the fleece in Spain is 8 lbs. from the ram, and 5 lbs. from the ewe. The staple differs in length in different provinces. The wool is usually white, but darker on the legs, faces, and ears. The frontispiece gives an illustration of these remarkable sheep in which the characteristic features are clearly seen. In the modern improved Merinos the large loose folds of the skin over most parts of the body have been bred out and the surface has become smooth, the same as in the Southdowns, which renders shearing much easier; but these characteristic folds are still always present on the breast and neck. In the frontispiece the old form of Merino ram is seen standing between the modern ram and the ewe.

These migratory sheep are divided into two classes, the Leonese and the Sorians. The former are the more valuable. They pass the summer in the mountains of the north, and the winter in the plains of the south of Spain. They leave their winter quarters about the middle of April, and occupy about six weeks on their journey. During their journey they are shorn in large buildings

built for the purpose. The sheep are packed close together the night before to cause them to sweat, which softens the yolk and renders the shearing operation easier. No less than 50,000 shepherds are employed in tending these sheep, which are divided into flocks of about 1000 each. Formerly it was supposed that this change of pasture was absolutely necessary for the animal to retain its fineness of wool; but it is now found that this is not the case, as some of the German Merinos, which were originally derived from Spain, and which are kept perfectly stationary, yield wool of equal quality.

For a long time the laws of Spain were very strict in regard to the exportation of these sheep, so as to prevent their introduction into foreign countries, and indeed, at one time, prohibitive,—the penalty being death in case of discovery. About 1723, however, they were introduced into Sweden, but have not flourished well in that country, probably on account of the coldness of the climate, which is not in favour of the growth of fine wool. Shortly afterwards they were introduced into France; but the breed was not kept pure, and deteriorated either through want of care or admixture with inferior races.

The Elector of Saxony introduced them into Germany in 1765, and in 1775 they were also taken into Austria, in both of which countries they have flourished in a remarkable manner, so much so that the German Merinos now more than rival the Spanish in the quality of the wool. The two classes of sheep which were introduced into Saxony and Austria are still perfectly distinct. *The Saxon breed* is called the Escurial. These sheep have longer legs than the Austrian, with a long spare neck and head with very little wool upon it, but the wool is shorter, finer, and softer in the fleece, which

weighs from $1\frac{1}{2}$ to 2 lbs. on the ewes, and 2 to 3 lbs. on the wethers and rams.

The Austrian Merinos are called Infantado or Negretti, and have shorter legs than the Saxon, with a comparatively short head and neck and short turned-up nose. The wool grows upon the head as far as the eyes and down to the feet upon the legs. It is very thick in the fleece and often very matted and tangled, while the yolk upon the wool is so stiff as to render washing difficult. When cleaned, however, the wool is very fine and long. The weight of the fleece is from $2\frac{1}{4}$ to $3\frac{1}{4}$ lbs. in ewes, and 4 to 6 lbs. in wethers and rams. These sheep, especially the Saxon, are very tender and require very careful attention both in regard to the pasture upon which they feed and the nature of the pasture ground. They are always housed at night, even in the summer except during the very finest weather, and are never returned to the pasture till the dew is off the grass. During the winter they are entirely kept within doors and fed with hay, straw, and corn. Although various attempts have been made to cross the Saxon and Austrian Merinos, no advantage has resulted from it, and the best results are in each case derived by keeping the breeds as pure as possible. Both these classes of sheep are stationary, and although originally derived from ancestors in the Migratory Merinos of Spain, have suffered no deterioration in consequence.

It seems, indeed, probable that the practice which is still maintained in Spain of moving the flocks is not a necessity of their existence in the best possible condition. The long, tiresome journeys, which occupy several months during the year, are always accompanied with many casualties and great mortality amongst the sheep, as well

as causing great inconvenience in the country through which they pass, which necessitates much land remaining uncultivated and special legislation to regulate the migration.

The Merino sheep was introduced into England by George III. in 1791—although a few sheep were obtained earlier—and the breed still remains, but has not been found so suitable in many respects as some of the native breeds, although crosses with it have much improved the quality of many of our native breeds. Although the quality of the wool on the English Merinos was quite equal to that obtained in their native country, it was found that they did not possess one of the necessary qualifications which in this country is essential, viz. the principle of early maturity and the general propensity to fatten. In all countries where the fleece is looked to as the great source of profit to the farmer, this is quite a secondary consideration; but in England the mutton is as valuable, or indeed more valuable than the wool, especially since the great reduction in the price of the latter; and hence many of our own breeds of sheep will always be cultivated in preference to the Merinos.

Notwithstanding this disadvantage so far as the meat-bearing qualities of the Merino are concerned, it stands first in the quality of the wool, and no sheep has had a more important part to play in the history of the industries of the world. The fineness of the fibre, the lustre of the hair, the unrivalled felting properties, and the great strength of the fibre in proportion to its diameter, all combine to render the Merino a typical wool; and the fact that admixture with almost all other races of sheep introduces many of its characteristics into their wool as well as renders them capable of extension over a very wide

geographical range, has made the Merino sheep one of the most valuable of all domesticated animals, and one which has rendered the very greatest service to the cause of human civilisation.

The number of sheep in Spain by the last return in 1900 was 13,359,473.

French Sheep

As we might naturally expect, a country so extensive and diversified as France contains a very large number of different breeds of sheep, and of late years especially considerable improvements have taken place in most of them arising from the introduction of foreign blood, which has been rendered easier by improvements in transit and the competition which the native wools have had to meet in the various markets. The original sheep were probably, as in England, of several varieties suited to the different physical conditions of the country. The mountain breed partook of the character of the usual mountain sheep which still linger in the districts of Navarre and Bearn, with long legs, thin body, and coarse fleece.

In Picardy the sheep closely resemble some of the English breeds, such as the Romney Marsh sheep, and indeed are a cross between them and the sheep of the neighbouring provinces of Flanders.

In Normandy there is a large breed of sheep which weighs as much as 15 to 16 lbs. per quarter, and which produces a fine long wool, and is also esteemed for its mutton, which finds a ready sale in the Paris market.

Along the coast of Bretagne, Poitou, Guienne, and Gascony the breed of sheep is entirely different, being much less and short-woolled, but the wool is fine and valuable.

At the lower or Basses Pyrenees the sheep yield wool which is fine in quality and from 6 to 7 inches long; but in the central or High Pyrenees a different breed is found, which somewhat resembles the Norfolk sheep, with black faces and legs.

In the district of Roussillon the presence of the Merino sheep may be distinctly traced, and many of the flocks are scarcely inferior to the Spanish Merino, from which, indeed, they were derived; the chief difference between them being that the wool does not grow so close in the fleece, but hangs in detached locks with a beautiful spiral waviness. The same class of sheep extend into Languedoc.

The whole district of Arles is famous for its sheep-farming, and the sloping pastures in the district of Crau, from the mountains down to the sea coast, abound in large flocks, which are hardy, healthy, and good wool-bearers. Most of the sheep in this district are migratory, being driven in summer from the plains of Arles and the valley of the Rhone towards the Alps, which divide Provence and Dauphiné from Italy.

The fine-woolled sheep of the southern provinces have had a considerable influence on the sheep of the inland districts northward, and most of the wool is in much repute. In Dauphiné it is finer than in most of the southern provinces. In Auvergne there is a mountain breed with black and white heads, but the wool is not much esteemed. The number of sheep in France in 1905 was 17,783,209.

Swiss Sheep

The mountains and valleys of Switzerland have long been distinguished for some of the breeds of sheep, the origin of which has no doubt been a breed which probably

originally came from Italy when the sheep was first introduced there from the East, or perhaps an older breed still, which may, like some of the Spanish sheep, have been indigenous to the soil, but now lost by crossing with more improved breeds. In many of the valleys the sheep are not unlike some of the English breeds, and have been imported, or sheep to improve them have been obtained, from Germany, Flanders, and Great Britain. As might be supposed from the general character of the country, a mountain breed flourishes best, and has been much improved since the introduction of the Merino sheep. In some parts of the country there are also flocks of pure Merino, whose wool is much sought after and wrought into the finer goods produced in the various cantons. The number of sheep in Switzerland was by the last return in 1906, 209,243.

ITALY

No country produces pastures which are better fitted for the feeding of sheep than Italy, and during the time of the Roman Empire the country possessed the finest breed of sheep which were then known; and they were watched and tended with a care which was unknown elsewhere, and the wool used for the manufacture of the very finest fabrics. With the extension of the Roman Empire, however, and the increase of Roman Colonies, the growing of wool was more extensively practised abroad, and the wools of Spain and Gaul were very largely used, and to a great extent supplanted those of native growth; the Italian sheep being more cultivated, like the present sheep in England, for the sake of the carcass for food. During the Middle Ages the foreign commerce of the Republics was such that they bought their wool from all the countries on the shores of

the Mediterranean Sea, and even from Britain, but with their decay the breeding of sheep was much neglected, and a deterioration in nearly every class of sheep in the country followed. Within comparatively recent years—since the unity of Italy has been attained—there has been a revival of both commerce and agriculture, and many flocks of sheep and rams for improving the breed of native sheep have been introduced from England and Spain. Piedmont, and the districts at the foot of the Italian Alps, have long been celebrated for a breed of sheep which are excelled only by the Merinos, from which they may have been originally derived; and various kinds of sheep famous both for long and short wool are found in the plains of northern Italy. The number of sheep returned as pastured in Italy in 1900 was 6,900,000.

GERMANY

As we have already mentioned, the Merino sheep has been introduced into this country and into Austria, and has flourished so well under the care and attention bestowed upon it, that the Saxon and Austrian Merino has produced even better and finer wool than can be obtained from Spain. There are several breeds of sheep found in the various provinces of Prussia, most of which, however, were of an inferior character; but since the introduction of the Merino, and most of all since the establishment of government schools of agriculture, a great improvement has been introduced into nearly all of them; and in addition to this, many of the long-woolled sheep, including the New Leicester from England, have been imported, which have materially tended to improve the native races. The same remarks apply to the Austrian as well as to the German Empire, and in every part of these two large continental states there is

an increasing number of sheep bred either from pure Merinos or crosses with the native races. In the Duchy of Holstein, in the north of Germany, a peculiar and valuable variety of sheep exists which is the descendant of a primitive breed. It is of a moderate size and yields fine wool, but not a large quantity. In this district also the introduction of foreign sheep has been attended with great success, and many large flocks are found both pure or mixed with the native breed. The number of sheep in Germany in 1904 was returned as 7,907,173.

Holland and Belgium

As might be expected, the sheep of these two countries more or less resemble the sheep of our own island, with which, especially the Romney Marsh sheep, they have been intermixed. Early in the last century a large sheep from Guinea was introduced, which has still left its traces, and, crossed with the English long-woolled breed, has produced a valuable sheep known as the Texel sheep. In Friesland there is a similar breed, but with more English blood, and resembles somewhat the Irish long-woolled sheep. In 1789 the Merino was introduced into these countries, but has never acquired the same hold as in Germany, although it has been used in several districts to improve the quality of the wool. By the last return in 1904 the number of sheep was 842,507, of which only one-quarter were in Belgium.

Russia

This vast empire has always been celebrated for its wools, and although many of them are coarse, yet from the extent of the country and the vast difference in climate which is found in a country stretching from the Arctic

Circle to the Black Sea and the Danube, we may naturally expect to find a great variety of qualities. The fact that very large numbers of the people are more or less of wandering habits, and their principal wealth flocks and herds, contributes to make it one of the largest of wool-growing countries. In the northern parts of the empire the sheep are small and short-tailed, and bear a coarse wool much mixed with hair and frequently of a very brown or mixed grey colour. On the banks of the Rivers Don and Dneiper and in the districts of the Ukraine, the sheep are larger and yield a better class of wool, some of it indeed of a fair quality when care is exercised in the management, and it can be used for the manufacture of cloth. The shores of the Baltic, and the islands in the Gulf of Finland, have long been celebrated for their wool, and in these districts the native sheep have been considerably improved by the admixture with superior foreign breeds.

The finest wool-growing district, however, in Russia, is the Crimea and the neighbouring provinces, where the climate and pasturage is of a character which is eminently adapted to sheep-farming, and the wool is usually shipped from Odessa. In the Crimea and neighbourhood there are three classes of sheep. The common breed has a long tail covered with fat, and is white, or black, or grey, with long coarse wool. These sheep are kept in very large flocks, and are removed from the mountains to the plains along the sea coast, according to the season of the year. There is a breed of mountain sheep which occupies the higher lands, and which yields a thick and rather fine fleece; and in addition to these two classes there is a breed which is a cross between these sheep and the Merinos, and which are receiving increased attention, and upon the cultivation

of which the increase in the export of better-class and finer wool from Odessa depends.

The last return in 1906 showed the sheep to number in

European Russia . . .	42,943,912
Asiatic Russia	18,605,339
Total .	61,549,251 including goats.

DANUBIAN PRINCIPALITIES

Along both shores of the Danube the sheep is extensively cultivated. The native sheep of this region —the Wallachian sheep—is a large, noble-looking animal, with spiral horns of large size and long silky wool, but the fleece is much deteriorated by a long growth of coarse hair. Until comparatively recent times, and especially on the Turkish side of the river, the state both of agriculture and sheep-farming was in a most primitive condition, but of late years the introduction of better-class sheep for breeding purposes, and specially the Merino, has tended to improve the native breed in every way. Indeed, in many districts the native is now either entirely displaced by the Spanish sheep, or a cross between it and the native, with the most beneficial effect on the wool; and this sheep, from its size and other useful characteristics, has spread into the neighbouring states and through Hungary and Bohemia. The Moldavian sheep differs from the Wallachian chiefly in the length of the tail and the form of the horn, which is not so spiral, and also in the quality of the wool, which is not so fine. Like the Wallachian, there is a great mixture of hair and wool; the hair being coarse and about 11 inches long, and the wool about 5 to 7 inches. A similar sheep also

exists in Bulgaria and Servia, and a smaller mountain breed in the Balkan ranges.

Turkey in Europe

On the Roumelian side of the Balkan Mountains, and in the central plains of Turkey in Europe, the sheep, as may have been expected from the general condition of the Turkish Empire, have been much neglected, and are in some places probably worse than they were centuries ago, but with the partial acquisition of independence improvements will be introduced and sheep-farming extended. The native sheep of the plains are of two kinds: one somewhat similar to the Roumanian, and another which is smaller and probably a cross between this and the Balkan sheep. In some of the islands of the Greek Archipelago the Musmon is still found, as in Crete and Cyprus; and in the latter also a peculiar breed which is distinguished by the possession of four horns, two of which stand erect forwards, and two curved downwards behind the ears.

Montenegro, Albania, and Greece

In the mountains of Montenegro and Albania there is a breed of mountain sheep which seems to be allied to the sheep found in the mountains of Greece; but the native sheep have in many instances in both these countries been superseded by better classes, which have either been imported or obtained by crossing the native breed with imported sheep.

Iceland Sheep

In the island of Iceland a peculiar breed of sheep exists—indeed there are two different breeds,—one

evidently the result of importation, probably from Norway or Sweden, and larger in size than the native breed, with a finer and whiter wool; and the other a small, active sheep, in colour varying from dun to black. One great peculiarity of this sheep is that it seldom has less than four and often as many as eight horns. When the horns are not more than five they are placed in one row, and all spring from the frontal bone as in the case of the native sheep of Cyprus; but when there are more than five, they are placed in two rows, one behind the other. They almost look more like goats than sheep, as the outer covering is long coarse hair with a close fine layer of wool underneath, which neither wet nor cold can penetrate. The ewes also, in districts where cattle cannot be kept, yield a valuable supply of milk, varying from two to six quarts per day.

Sweden, Norway, and Denmark

The native sheep of these countries are not a very valuable breed, but they are very hardy and easily withstand the severe winters, besides yielding a sweet and nourishing mutton. They are usually of medium size, with slender bodies, which are not readily fattened, and long bare legs. They have a small head and short horns, and the fleece is only sparse and open, and frequently mixed with much hair, especially in the hilly districts and upon poor pastures. In the islands on the coast of Norway there is a breed of wild sheep which are sometimes caught and shorn by the natives, but the wool is wild and coarse.

Sweden was the first country to see the advantage of improving the native breed, or else supplanting it with

the Merinos, and as early as 1723 these Spanish sheep were introduced, and the result was a great improvement in the native breed and a great increase in the manufacture of woollen goods, in consequence of the improvement in the wool. These sheep were also introduced into Norway at a later period, and in both countries great attention has been paid to their cultivation, so that they now exist in great numbers.

The Danish sheep originally were not unlike those of Norway and Sweden, and have been much improved by the introduction of Merinos, so that now considerable quantities of fine wool is exported from Copenhagen to Great Britain and Germany.

II. ASIA

We have already pointed out that there is strong reason to believe that many of the Asiatic varieties of the sheep have taken their origin from the Argali or wild sheep of the Asiatic Mountains, which extends its range from the Caucasian Mountains to the shores of Kamtchatka, along the whole chain of mountains which run along central Asia. We have already given a description of this animal (p. 111) and of its habits, and it is not necessary, therefore, to refer to it further.

The general character of the Asiatic domestic sheep is somewhat similar to those which are found in *Palestine and Syria.* In those changeless countries they have probably altered little in character since the days of Abraham. A few of the fat-rumped, but more of the fat broad-tailed variety are seen. In the latter the carcass is more or less neglected, and the hairy-woolly fleece is coarse and comparatively valueless, while the

fatty portion of the tail is increased to one-fourth and even sometimes one-third of the total weight of the sheep.

The fat-rumped sheep have an accumulation of fat, commencing at the posterior part of the loins, swelling gradually into a considerable mass towards the rump, which presents two considerable enlargements of a more or less globular form. This sheep extends through the northern part of Asia and into Russian Europe, and is the prevailing sheep of which the flocks of the Kalmucks and Turcomans and almost all the wandering tribes are composed. It is influenced to a certain extent by the climate and pasturage, but no attempts have been made to improve the breed by admixture with other races; and the fact that it can travel long distances, endure great hardships, and yields a plentiful supply of milk and coarse wool for the coarse fabrics used by the wandering tribes, renders it one of the most useful of the domestic varieties. In some districts of Russia, however, with care and cultivation, this sheep has been caused to yield fine wool with only a small admixture of hair.

The broad or fat-tailed sheep is probably a variety of the last named, and is found in Palestine, Syria, and Persia. These creatures have a monstrous round of fat like a cushion in place of a tail, which sometimes weighs 30 or 40 lbs. The wool of these sheep is coarse, much tangled, and felted and mixed with coarse dark-coloured hair. Large quantities of the wool of this sheep are exported from Bagdad, and the breed is found in all parts of Asia as far as China. Fig. 44 gives a fair illustration of this remarkable sheep.

As the majority of the Persians lead a pastoral life, much attention is paid to the breeding of sheep, and the

best are found in the district of Kerman. Here the wool is fine in quality and is manufactured into goods which rival the beautiful goods of Cashmere.

The sheep in this district bear a fine spirally curled wool of a grey, or mixed black and white colour. They are below the ordinary size and their fleeces supply most

FIG. 44.—The Fat-tailed Sheep.

of the wool from which the fine felt carpets of Persia are made.

TIBET SHEEP

The sheep in this region are very numerous, and are chiefly a small variety of the fat-rumped Persian sheep, and this class extends through Afghanistan and into the north of China. In some of these sheep there is a small

portion of wool growing at the roots of short hair, but in others the wool is both long and fine, and out of the long wool, after careful separation from the hair, some of the fine shawls of India are manufactured.

India

The same variety of sheep above mentioned are found in northern India, and the class of wool is the same, but in some districts, such as Nepal, there exists a small class of sheep which are well cultivated and yield a very fine class of wool, which is used in making a variety of fine fabrics. These sheep, however, cannot endure the great heat of the plains.

In the Deccan there is another variety of sheep which is extensively reared. It has short legs, short thickish body, and short horns, with short black wool. Attempts have been made to introduce English sheep into India, but in the tropical regions there is always difficulty in regard to pasturage, and the author has not heard what success has attended the endeavour. It is impossible to leave India without mentioning the Cashmere goat, which is found in the district of that name. It is allied to the native Tibet goat, but rather smaller. It is a fine-looking creature, with very large horns, which curve backwards and often extend half the length of the animal. The hair is longer than that of the Angora goat, which yields the mohair of commerce, and is destitute of the undulating curves which are the true distinction between hair and wool. This hair varies from 6 to 18 inches long. The finest only grows upon certain parts of the goat, and it is said that a single goat only yields about 3 to 4 ounces. The strictest watch is kept to prevent these cultivated goats from being

exported, and it is from their hair that the fine Cashmere shawls are made, which are unrivalled for texture, colour, and design. The number of sheep and goats in British India was in 1906 returned as 18,029,181.

Chinese Sheep

The vast empire of China possesses several distinct varieties of sheep. In the north and along the borders of Tartary the fat-rumped and fat-tailed breed is found. The same is also found in the south, where, in different situations, it produces almost every variety of wool. In some districts in the south there is also found a small variety of sheep which almost resembles some of the English breeds, and from the wool of which the natives make a fine class of serges. The larger varieties yield wool from which strong felted carpets are made. There is also in China a long-legged sheep which seems to resemble the African Adimain sheep. The tail is long and the wool short and coarse. Some of the sheep in the northern districts have four and even six horns, the same as the Iceland sheep.

III. AFRICA

The general character of the sheep in the northern districts of Africa, around the basin and in the valley of the Nile, greatly resembles that of Palestine and Persia, modified to a certain extent by the difference in climate.

Egypt, the Soudan, and Abyssinia

Along the borders of the Red Sea and the eastern coast of Africa the general condition of the sheep is not

satisfactory, as it is much neglected. In Egypt the condition is rather better, although the rearing of sheep is not largely carried on. The fat-tailed sheep prevail in Egypt, but those with long tails nearly reaching the ground are more numerous than the broad-tailed. In Upper Egypt the sheep are more numerous and of a large size, with tails which weigh from 18 to 25 lbs. Also the fat-rumped sheep, which are rather smaller than the Persian. Beyond the confines of Egypt and stretching onward to the mountains of Abyssinia there are many tribes who possess large flocks of sheep, some of which are well looked after and produce good wool. The Abyssinian sheep are somewhat similar to the native Persian, with an external covering of hair, which has, however, frequently a fine lustre and softness. In the mountains, also, are found the many-horned sheep, similar to those which are found in the rocky portion of the deserts of northern Africa.

Morocco, Algiers, and Tunis

The native sheep of this district are only of a very poor character. They are of the middle size, with an arched forehead, pendulous ears, and shaggy hair, with long uncovered legs. They are found in large numbers in the oases which abound round the wells in the desert which stretches from the coast of the Mediterranean Sea inward towards the south. Since the colonisation of Algiers by the French attempts have been made, with success, to introduce better breeds of sheep, and the Merinos and other cultivated races have been imported, so that in some districts really good wool is now grown. Whether any attempts have been made to improve the native breeds the author cannot say, but immediately we pass from the places

in contact with European civilisation to those where native rule pertains, we find all traces of improvement lost. In Morocco and Fez there is a considerable manufacture of coarse woollen goods, and also of felted materials made from the finer parts of the fleece, of which we have the best example in the felted skull-caps that are so universally used by the Turks and Egyptians. Some of the native sheep of Tunis have been imported into Spain and America, and, crossed with Merino sheep, have been made to produce a good class of wool.

West Coast of Africa

Along the west coast of Africa several distinct breeds of sheep are found. In Guinea and the Slave Coast there are two which are quite different. One is of small size, and somewhat resembles the European sheep, and the other, which is most numerous, is larger and of a different character. The male is horned and the female generally hornless. The colour is usually grey, with black distributed about the head and neck, and a mane of long, silky, white hair. There is also a sheep which has a large quantity of hair flowing down towards the brisket, and which gives it a singular and curious appearance, and, one traveller says, they have so little resemblance to those in Europe that unless they were heard to bleat it would be difficult to tell what kind of animals they are. In Angola a very singular sheep is found, called the Zunu, which is found in no other part of the world. Its legs are long and slender, but muscular and strong. There is a slight elevation of the withers, the chest is narrow and flat, and the false ribs project and give the animal a strong resemblance to the Zebu. The fat is singularly distributed over the body and about the neck, which has given it the

name of the goitred sheep. The body is covered with soft, short, pale brown hair, mixed with a fine undergrowth of wool. Somewhat similar sheep, but differing in colour and general form, are found along the basin of the Congo.

Cape Colony and Natal

The most important sheep-rearing district in Africa, however, is the Cape Colony and Natal, with the adjacent districts. The native sheep is of the broad-tailed variety, with long legs and a small body, with the fat collected mostly on the rump and tail. They are of every variety of colour, and covered with a strong frizzled hair, with the undergrowth of wool mixed with it.

When the colony was in the possession of the Dutch, they introduced improved sheep from Holland and Spain, and sheep-farming became a very large industry. When the colony passed into the hands of the English this industry increased in importance, and now wool of the very best quality, and in very large quantities, is exported to Europe.

When the Merino was first introduced there was considerable prejudice against it, but its success in one district gradually led to its introduction, along with Southdowns and Leicesters, into all the others. Attempts have also been made to introduce the Angora goat into this colony, and this has now succeeded, and large quantities of goats' hair, which is as fine in quality as the native Mohair from Asia Minor, are now imported from Cape Colony into the United Kingdom. Very fine samples of this mohair, derived from crosses with native and Angora goats, were seen by the author in the Indian and Colonial Exhibition in 1886, and since that time the trade has largely increased.

Some idea of the great importance of this industry in the colony may be gathered from the fact that in 1905 the number of sheep and goats in British South Africa, including the Transvaal and Rhodesia, was 17,982,677.

IV. AUSTRALIA AND NEW ZEALAND

Nowhere in the world has sheep-farming been carried on with greater success or on a larger scale than in our Australasian Colonies, and nowhere has the effect of climate and breeding been more marked in the improvement of the wool.

The settlement in New South Wales, which was originally intended as a convict station, and which is now the flourishing colony with Sydney for its capital, was the first place where sheep were introduced into the island. There were no sheep native to the soil, and the first were introduced from India. Those introduced were of poor quality. They had large heads, Roman noses, and slouch ears. They were narrow in the chest and shoulders, with long legs, high curved backs, and a coarse hairy fleece, more resembling goats than sheep. Even these sheep, under the influence of the splendid climate and rich pastures, became essentially changed in character, and in the course of a few years lost all their hair and increased the growth of wool, which was likewise much improved in quality. Southdowns and Leicesters were then introduced, and the crosses with these produced a fleece equal in fineness and value to that of the pure breed of these sheep in England. The success of the Merino sheep in every part of the world led to the introduction of these into Australia, and the third or fourth cross with the prevailing sheep of the colony produced an animal with the fleece equal in quality to the pure Merino

in Europe, and the wool of the pure breed seemed to improve as much in quality as the native wool had done. Henceforth the production of wool became the great staple trade of the colony, and the millions of sheep which cover the pastures of New South Wales, Victoria, Queensland, New Zealand, and Tasmania are second to none in the world; some even rivalling the finest Saxony. The history of one colony is the history of all, and the immense increase of manufactures in Europe has sustained an ever-increasing demand for the splendid wools which are now exported. During the last few years the greatest attention has been paid to increasing the size of the sheep, and in many districts the fleece is now twice the weight that it was ten years ago. This is of the greatest importance, because the same weight of wool is now obtained from a fewer number of sheep; and in a country where, from the frequency of drought, pasture is often very variable, this is a great desideratum.

The rapid decrease of time required for the voyage to and from Europe by the introduction of steam, and the opening up of an entirely new outlet for the carcass of the sheep in the tinned and frozen mutton now so largely used, have afforded a new stimulus to the increased cultivation of sheep, which is rapidly telling in every part of the world.

In 1906 the number of sheep returned was as follows:—

Victoria	12,937,440
New South Wales	44,132,421
Queensland	14,886,438
South Australia	6,661,217
Western Australia	3,340,745
New Zealand	20,108,471
Tasmania	1,729,394
Total	103,796,126

Including the wool sent to North America, the total quantity sent from these colonies was one million and twenty-six thousand bales.

V. AMERICA

We have already pointed out (p. 112), that the Big Horn or Rocky Mountain sheep is a native of America. But few of these creatures have ever been tamed, and as wool-bearing animals they have really no interest.

UNITED STATES

During the time that these States were colonies of England various classes of sheep were introduced, and in many of the States sheep-farming is an important industry, although it has hitherto been more or less subordinate to the growth of cotton and corn. During recent years, however, great efforts have been made to improve the character of the sheep. This has been stimulated by the increase in manufactures which has arisen since the war between the North and South, and the imposition of protective tariffs on all imported manufactured goods. At the present time there are many large flocks of first-class sheep of various kinds found scattered over the country, and extending into some of the better parts of Canada.

No country in the world surpasses some parts of the States as a field for sheep-farming. The country is undulating or hilly, with the finest herbage and abundance of water. Recent experiments which have been made in the South with a view to rotation farming in the cotton-fields, and which have demonstrated that sheep and cattle can be fed on the green parts of the cotton-plant and the

cotton-seed cake after the oil is expressed, open up a wide field for an extension of sheep-rearing, and there can be no doubt but that in the future America will take an increasingly important place as a wool-producing country in every quality which can possibly be required.

The author saw the statement in a Boston paper (*Boston Journal of Commerce*), that this year the production of American clothing wool would exceed that of every country in the world except Australia; and the number of sheep in the United States was returned in 1907 as 53,240,282. Whereas in 1870 it was only 28,477,951, which shows the very rapid advance of wool-farming in the States. In addition to the large increase in the yield of wool, the Angora goat has been introduced into suitable localities in Texas, Georgia, and elsewhere, and very large quantities of mohair are now produced, which will probably render the country in a few years quite independent of foreign supplies.

South America

Many of the States of South America possess large flocks of sheep, which serve for the purposes of native manufacture and for export. Most of the sheep are the offspring of those which were originally introduced from Europe when the Republics were Spanish colonies, and they therefore partake of the character of the European wools. The immense plains which abound on the Atlantic coast form one of the best rearing grounds for sheep in the world, and some of the finest wool is now exported from the district watered by the River Plate and other regions. Returns are not available for all of the States, but in Mexico and Uruguay alone the return in 1902 was 21,351,501 sheep.

ALPACA

Before concluding our notice of the wool-bearing animals in America, it is impossible not to notice one which has played such an important part in the manufacture of Bradford goods, viz. the *Auchenia Paco*, which although usually referred to as a goat, belongs to the order Auchenia (from the Greek word *Auchen*, the neck), a genus of ruminating quadrupeds, of which the Llama is the best known. It is exclusively South American, and is found in the lofty ranges of the Andes. The members of this genus are allied in character to the camel, and may be regarded as the American representatives of that family. They possess a stomach somewhat similar to the camel, and resemble it in general form, except that they are smaller. They have a long neck, small head, prolonged and movable upper lip, and small apertures of the nostrils. They differ from the camel in the dentition, and partly in the more cloven feet and movable toes. The nails are stronger and curved, and each toe is supported behind by a pad or cushion of its own. Considerable doubt exists as to the number of species in this order. The Llama and Vicugna are certainly distinct, but it is doubtful whether the Alpaca is not a mere variety of the Llama.

The Alpaca is smaller than the Llama, and the legs and breast are destitute of callosities. In form it somewhat resembles the sheep, but it has a longer neck and more elegant head. The head is carried erect, and the eyes are very large and beautiful. The general form of this creature is illustrated in Fig. 45. It is remarkable for the length and fineness of the wool, which is of a silky texture, with a very bright and silvery, almost metallic lustre. As we

shall afterwards see, when examined under the microscope the alpaca fibre seems to occupy a position intermediate between wool and hair, indeed, having many of the essential features of the latter rather than the former, as the epidermal scales are closer in their attachment to the stem of the fibre. If the creature is shorn each year, the length

FIG. 45.—The Alpaca Goat.

of the fibre reaches eight inches, but if allowed to grow it will attain a length of from twenty to thirty inches. The wool is not so curly as the wool of the sheep, but fine and very strong in proportion to the diameter. The colour varies very much. Some of the goats are yellowish-brown, and some grey, and even white, while many are found which are quite black. The late Sir Titus Salt was the

first to introduce this important fibre into use as a material for textile fabrics. The quantity of Alpaca and Vicugna imported into Great Britain in 1907 was 4,326,796 lbs., and of Camel's hair 8,896,375 lbs.

Mohair

Simultaneously with the great increase in the demand

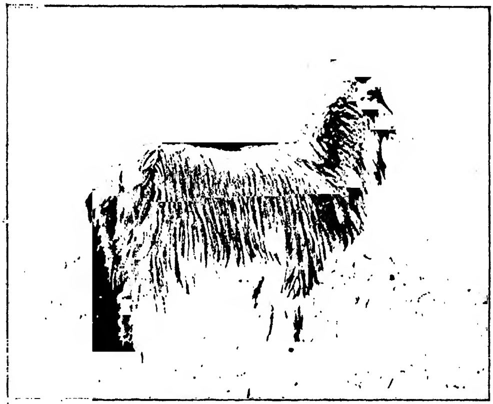


FIG. 46.—Angora Goat.

for lustre goods which led to the rapid rise of the alpaca trade, there has been a very large use of another and allied fibre—mohair.

This fibre is the wool of the Angora goat, a creature whose native home is in the mountainous district, in the interior of Asia Minor, and of which Fig. 46 gives the general features. The centre of the district is

the town of Angora, about 220 miles from Constantinople, from which the goat derives its name. The climate and soil seem to be peculiarly favourable to the growth of long silky hair, as many of the cats, dogs, and even the rabbits and rats of this region are famous for it. The Angora goat is a fine, noble-looking animal, with large horns which are curved back over the neck, and its fleece is composed of long, beautiful silky hair, varying in length from 6 to 8 inches or more. This hair, however, is a true wool, since it possesses a curly structure, with a fine development of the epidermal scales and a bright metallic lustre. From the earliest times this district has been famous for the production of a superior fine yarn and fine wool goods. Endeavours have been made to acclimatise this goat elsewhere, but for a long time without success, as, when removed from its native mountains, the wool deteriorated and lost its distinctive features.

This goat has been introduced into Cape Colony, where in its pure state, and mixed with the native African goat, it produces a fleece which even exceeds in quality the native mohair, and large quantities of this material are now exported to England. As we have already noticed, they have also been introduced into the United States, and large flocks, which are continually increasing, are now to be found there in suitable positions. The quantity of mohair imported into Great Britain in 1907 was 25,308,026 lbs.

CHAPTER VIII

SHEEP AND WOOL CULTURE

It may not be uninteresting in a book of this character to include a chapter on the qualities which are most desirable in sheep and wool, and the methods in which these may be best attained and perpetuated.

From what has already been seen, it is quite clear that amidst the great variety in the breeds of sheep and in the character of the wool which they produce, arising from difference in nature and environment, there are some which possess more desirable qualities than others, and are therefore the models whose characteristics are most sought after.

Classification of Wools.—From a manufacturer's point of view it may be said that all wool, irrespective of its quality, and looking at it from a purely mechanical standpoint, may be divided into two great classes, which correspond with the two different classes of yarns made from wool. These are called *worsted yarns*, where the fibres are all arranged parallel to each other before the twist is put in; and *woollen or carded yarns*, where parallelism of the fibres in the yarn is not required.

1. *Long Wool.*—Where the staple is of such a length that it can be used in the preparation of worsted yarns,

and the strength of the yarn is less dependent on the felting property of the wool than upon the length of the fibres, which obtain on this account a greater holding surface when the twist is put in, and which require to be treated by machinery in which the long fibres in the fleece are selected and the short ones removed before the spinning process is reached. These wools reach their highest perfection in the Lincoln, Leicester, Cotswold, and other deep-grown wools, and in their crosses with the Merino and other breeds, in which the length of wool is retained and greater softness and fineness introduced into the fleece, as in the cross-bred Colonial wools.

2. *The Short Wools.*—Where the fibres, although uniform in length, have a much shorter staple and a higher felting quality, and, when made into yarn, are not treated in machinery so much to obtain parallelism of the fibres, but depend for their strength upon the entanglement of the fibres and a certain amount of felting action which knits them together rather than upon the holding quality derived from the twist; and generally in the goods made from these yarns the felting process is increased by fulling and other means, which renders the texture of the cloth more felted and dense.

This short wool is typically represented by the Merino, Southdown, and Shropshire fleeces. There is a borderland where these two classes of wool meet, and where portions of the fleece can be sorted out and used for combing purposes and the making of worsted yarn, leaving the shorter portions to be used for carding and woollen yarns. These are sometimes called middle-woolled sheep.

Characteristics of Good Wool.—Whether the wool be long or short, however, there are certain properties which must be possessed by the fibre of the wool, from whatever

source it is obtained, and which, for their respective kinds, may be summarised as follows:—

1. All the fibres in the fleece must be of as uniform a length as possible over the largest possible area.

2. The diameter of the fibre must be as fine as possible for the character of the fleece, and uniform and sound throughout its entire length.

3. The staple must be evenly distributed over the whole surface of the body, and when the suint or fat is removed the staple must be left free and open.

4. The fibres must be supple, elastic, and of uniform strength, and free from any hard or brittle parts.

5. For the class of wool the scales on the surface of the fibre must be as numerous as possible, of uniform size, and closely adherent to the surface, so as to prevent felting in the fleece or the accumulation of dirt under the free margins.

6. Other things being equal, the fibre must be of good colour and possess as high a lustre as possible.

7. The wool must have a soft lofty feel when handled, and also be elastic, resilient, and well-fed.

It must be the aim of the sheep-farmer to attain these various points in the highest degree, and just in proportion to this will the price of his wool rise in the market.

In order to be successful in this respect constant care and attention are necessary, and two considerations in regard to the sheep are most essential:—

1. **Selection of Breed.**—The sheep must be of such a breed as will flourish best in the particular district in which the farmer lives.

No animal is more responsive to environment than the sheep, improving in every quality when this is suitable to its peculiar requirements, and none deteriorates more

rapidly when the circumstances are adverse. Fortunately the farmer has an almost unlimited choice in this respect, and whether he lives amongst the wild hills, or in the quiet valleys where the rich grass land is well watered by the rivers, or whether the pasture is poor or rich, by the sea-side or inland, he is able to select a sheep which is suited to the geographical and climatic conditions, and thus he can secure the best results attainable in that locality. As a rule, in the choice of a sheep it is safe to select a similar class to those which are already being run in that district, and if there is not this experience as a guide, it is best to select a sheep from a district which, although similar in character, is rather worse in regard to climate and surroundings, so that when it is placed in its new habitat it is in a better position and not a worse one. Perfectly pure breeds of sheep are more tender and require better conditions than half-bred or crosses.

2. **Character of Breed.**—That the sheep should be of the best class of their respective kind and kept in the best condition.

It pays no farmer to neglect his flock, and deteriorated, ill-conditioned, and unhealthy sheep will pay nobody, and, as in every other business, good management is the essence of success. Apart, however, from the best class of sheep for the locality being run, there must be with every farmer a consideration given to the commercial fitness of the sheep, arising from the character of the markets available. With the British and Colonial farmer this presents a most important difference, which, however, as easy transport and communication improve, tends to become more assimilated and uniform. The British farmer is close to the best markets in the world, both for the carcass and the wool, and hence, apart from stock-breeding for sale and stud-farms, he has to

consider the weight and quality of the mutton quite as much as the quality of the wool, and it pays him best to select those sheep where dead weight and early maturity secure for him a quick return on his capital, quite as much as the quality of the wool. Hence, for commercial purposes, cross-bred sheep are probably best in this country, because although the farmer may get less for the wool, he gets more for the meat, and the sum of the two is probably greater.

The crossing of a pure-bred sheep such as a Southdown with a Lincoln or Leicester increases the size and weight of the sheep and also the weight of the fleece, and although the quality is not so good, the increased weight of wool makes up for this. First and second crosses seem to be the point at which the best results are obtained, as the mutton still retains the delicate flavour of the purer breed, and yet the increase in size is not sufficient to cause great deterioration in the quality of the wool, although it changes in character from the short to the long variety. Little advantage is gained by going further.

In the colonies and other distant countries which depend on the British or European markets the case is widely different. The carriage of the wool from the farm to the market is an important item, and it will be readily seen that the higher the quality and the less the weight the better the commodity will stand the charge. There are many districts where the distance from the farm to the port of export is very great, and where the carriage and commission run into pence per pound, and here it pays to give the greatest attention to the quality rather than the quantity, both in the carcass and fleece. Formerly in Australia, in many districts, the transport of the carcass to the consumer rendered it of little

value, but now the introduction of cold storage in the transport ship, and the possibility of exporting in the tinned state, has rendered the question of a compromise in quality somewhat similar to the Colonial as to the British farmer. Each must be guided by the circumstances of his own case.

Scientific Sheep Culture.—Great Britain, although small in area when compared with other large sheep-breeding countries, contains within its borders a larger number of pure-bred varieties than any other. It is the native home of the long-woolled breeds, and it was in this country that the scientific culture of sheep was first systematically practised, and the name of Robert Bakewell of Dishley, near Loughborough, will be honoured by every lover of sheep as the master pioneer in this respect. He grasped the great fact, now so familiar to biologists, that the properties of the parent may be transmitted to their offspring until fixity of type is attained, and his success in the Improved Leicester was such that he was the first to obtain 1000 guineas for a ram in 1789, which represents a much larger sum at that time than to-day. Afterwards, when the scientific culture had spread over a wide area, it was found advantageous to introduce fresh blood into the sheep, and this laid the foundation of still greater improvements, and to-day the types of sheep may almost be said to represent a manufactured article, in which the qualities of sire and dam and the properties of other breeds are judiciously blended in one perfect whole.

The Shropshire breed (see Fig. 38), which has received its distinctive and admirable qualities, is a good instance of this perfection, attained within the lifetime of a generation. In the great central districts of the United Kingdom no sheep flourishes better, and it has shown a remarkable

power of adaptation, even in districts where the climate and soil vary very widely in character,—a power of adaptation which has enabled it to acclimatise itself on the Continent of Europe, the United States of America, Canada, and Australia. For the same weight and quality of food no sheep yields better results either in the meat or the wool.

In Great Britain there are now at least twenty distinct varieties of sheep, and each of these flourishes best in certain districts, and the stud-farms of this country, with the exception of the Merino, are the source from which the supplies of sheep, both sire and dam, are drawn upon to maintain the standard of excellence in all parts of the world.

Maintenance of Standard in Flocks.—When the farmer has selected the class of sheep best suited to his requirements, it is necessary for him to be constantly watchful to maintain the standard of his flock, and this can only be done by the most careful attention. The price of this, like that of liberty, is eternal vigilance. He must watch carefully the character of each individual, and compare the fibres of the fleece with the standard already laid down as to the requirements of perfect wool. The slightest deterioration must be at once corrected, and weak or faulty members removed from the flock. Any deterioration in the character of the lambs must at once be checked and corrected. In correcting these the class of sire is, as a rule, more important than the dam, and the ram must be chosen which is strong in the points where the ewe is weak. A weak constitution is usually the cause of the deterioration in the wool, and hence the ram chosen must be young and vigorous, with robust form and chest development, and his use carefully regulated, so as not to impair his strength. Good food, careful attention to

health, and, in the more domestic breeds, shelter from inclemency of the weather and storms, are essential if the highest standard is to be attained.

Importance of Regularity in the Clip.—The manufacturer looks exclusively at the wool and pays no regard to the mutton, and with reference to this it is most important that each individual fleece shall be as much alike the others as possible, so that in examining one fleece he gets a fair sample of the remainder. Regularity in this respect renders the sale of any particular wool much easier.

Parasites.—Cleanliness and freedom from any of those deteriorations which arise generally from the presence of parasites on the skin is essential.

The skins of all animals which possess a hairy or woolly covering, which affords cover and nourishment for the pests, are always liable to harbour various forms of these parasites, and the sheep is no exception. While these by means of puncture injure the pelt or skin, their action on the wool is reflex and not direct. Any injury to the skin also interferes with its appendages, directly by interfering with their growth, and indirectly by interfering with the health of the animal and rendering it nervous and restless, unable to eat or rest well, and so undermines its general health; and immediately deterioration of the fleece begins. The vigour of the growth of the fibre is checked, the secretion of suint and other oils becomes less, and the fibres are then liable to mat and felt; or they lack nourishment and become tender, irregular, and harsh, with distortion, and atrophy or hypertrophy of the constituent parts.

It is not necessary to specially mention the variety of these parasites, as they can be found detailed in any manual of the sheep, but the remedies which are employed to limit or destroy them require to be considered, because they are

brought into contact with the fibres of the fleece, and upon their proper character and use depend the preservation or injury to the wool, and so its value to the manufacturer may become much less.

To destroy these parasites or render their existence on the sheep impracticable, without at the same time injuring the health of the sheep or damaging the fibres of the wool, is not by any means an easy task. Before the matter was investigated and provided for by scientific methods and with due regard to physiological considerations, much injury was frequently done to the wool, and serious consequences resulted to the manufacturer. For perfect removal it is necessary that both the mature and early forms of these pests must be eradicated, and this can now be completely accomplished by means of scientifically compounded preparations which may be used as washes, which neither injure the wool nor the health of the sheep.

Injurious Smears. — In the old days the principal preparations were smears compounded of tar and butter, and various products of tar distillation, and washes of tobacco infusion, or crude arsenical or mercurial preparations, all of which were either injurious to the skin or the wool. The tar was specially objectionable, as it could only be removed by hand clipping, and, if left on the fibre when it went into the manufacturing process, occasioned damage both to the machinery and to the goods made from the yarn. All these materials must be carefully avoided.

The use of alkalies or acids such as soda ash, potash, or strong alkaline soaps, and of carbolic and other acids, must be avoided also, as they act injuriously upon the suint and also upon the fibre itself, and render it tender and lustreless. Above all, lime must be avoided, because along with the constituents of the wool it forms insoluble compounds,

which find lodgment under the scales of the fibres and greatly interfere with any subsequent dyeing process. Mixtures of lime and sulphur were at one time largely used, specially in South Africa, and were the cause of great damage to the wool and its reputation.

Arsenical Dips.—The material now most used in the preparation of dips is undoubtedly arsenic and its compounds, and from personal inquiry the author found that the largest portion of the best wools, both in this country and the colonies, were from flocks where these were exclusively used, and these wools fetched the highest price in the market.

Arsenious acid, the white arsenic of commerce, is insoluble in water, and is a strong and deadly irritant poison, that attacks the surface of the skin, and by union with the fluids of the body forms soluble compounds, which by absorption may enter the circulation, and especially when applied to sores.

Scientifically compounded with alkalies and sulphur, it is soluble and forms the base of the most successful dips, and its action is thus restrained so that it becomes beneficial rather than deleterious, and it is then removed from the fibre easily in the process of washing. All reliable works on sheep-farming now give full details of the best methods of applying these preparations.

Time for Dipping.—The best time for dipping appears to be immediately after clipping, when the wool is short and the removal of the suint is soon replaced; and a second dip is usually given in autumn just before the severe weather commences, and this prevents contagion when the sheep have to be folded during the winter season. The skin being clean and healthy, the growth of the new wool is secured in its best condition.

Washing of Sheep.—Apart from destruction and prevention of parasites, there is always more or less dirt, such as soil, clay, manure, etc., gathers on the fleece, especially when run on arable land, as during the late autumn and winter feeding. That the washing of wool is injurious to the fibre by removing the natural preservative, the suint, is undoubted, as the wool is then more apt to felt and mat, and rendered less fit for the manufacturer.

One of the largest wool-combers in the world told the author that they could get far more satisfactory results if the wool was delivered to them unwashed, as it was often spoiled before it came into their hands. Washing, however, in many cases seems for many reasons to be necessary, and is resorted to by many of the most successful wool-growers immediately before shearing. No harm whatever comes to the wool from washing the sheep after clipping, but it is unnecessary when dipped at that time. The question whether washing was resorted to before clipping was asked of twenty representative British farmers, and of these six replied they washed and thirteen that they never did. One said he never washed show sheep. It may be noticed that those who washed were all owners of long deep-grown wool flocks, which does not felt as easily as the finer short wools, and these long wools would therefore suffer less.

Where washing is resorted to, it ought always to be in running water, so that a fresh supply is always reaching the sheep, and no rubbing must be used, as it felts the wool. As soon as the sheep has come out of the water and shaken itself, it ought to be placed in a clean dry field or straw yard, and not permitted to go on to earth or loose soil, and must be allowed time to restore the suint before shearing.

Shearing.—The shearing time differs in different places, and it is now almost universally done by clipping machines and not by hand, so that most causes of defects arising from careless hand-clipping are removed; but the condition of the wool at the time of clipping and its handling and preparation for the market are often very faulty.

One of the most serious matters is the presence of foreign matter, and especially that of vegetable origin, associated with or entangled in the wool. Farmers are frequently not aware that animal and vegetable fibres cannot be dyed together, and that any vegetable fibres or pieces, such as shaws, birs, hemp, or cotton, or other materials must be entirely absent, or else defects will appear in the finished goods. It is true that these can now be entirely removed by the process of "carbonising," which consists of treating the wool with dilute mineral acid, usually hydrochloric acid, and then subjecting it to a sufficiently high temperature to destroy the vegetable matter, so that when dried and the wool shaken all the carbonised matter falls out as dust. This process, however, costs when entirely carried out about 1½d. per lb., and this must be taken into account when purchasing the wool, and the farmer has ultimately to bear the loss.

Preparation of Wool for the Market.—This is a very important matter, and many clips are rendered less valuable in consequence of carelessness in the handling and packing. So serious is the question, that some time ago the Bradford Chamber of Commerce appointed a committee to report on the subject and make recommendations to the wool-growers, and their communication was so practical and valuable that the author makes no apology for including it as the conclusion of this chapter.

FARMERS AND HOME-GROWN WOOL

Recommendations by the Trade

Owing to various occurrences, which have from time to time been noticed in the *Bradford Observer*, it was thought desirable at the conclusion of the country wool season in 1900 that a meeting should be held for the purpose of discussing some objectionable practices which appear to be on the increase. In consequence, a large and representative meeting of members of the wool trade from all parts of the United Kingdom was held on December 6, 1900, in the rooms of the Bradford Chamber of Commerce, at the invitation of the Wool Trade Section of that body. At that gathering a committee of gentlemen representing the wool trade of the country was appointed to consider the whole question of false winding of fleeces and the conditions of auction sales. Numerous meetings have been held, and the following is a summary of the deliberations and conclusions of the Committee. It is hoped that British and Irish wool-growers will take careful note of the remarks which have been here made, and will receive them in the spirit in which they are offered.

As the *Mark Lane Express* very properly says in an article on the subject:—"The wool-buyer is just as much necessary to the farmer as the corn-dealer. He will also find the wool-grower equally necessary to him. When two classes of persons are necessary to each other, they will find it well to try and be reasonable with each other. We trust that such a spirit will actuate both sides in this matter. If it does, there ought not to be the least difficulty in arriving at a satisfactory solution."

The following is the summary of the conclusions of the Committee referred to:—

For many generations it was the pride of the British and Irish agriculturists that their wool was got up for the market in a manner superior to that of any other country.

In their early efforts to arrive at this pre-eminence our ancestors obtained the assistance of the law, and an Act of Henry VIII. provided that "No person shall wind or cause to be wound in any fleece any wool not being sufficiently rivered or washed, nor wind nor cause to be wound within any fleece clay, lead, stones, sand, tails, deceitful locks, cots, lambs' wool, nor any other deceitful thing whereby the fleece may be more weighty, to the deceit and loss of the buyer."

The penalty for infringement of this Act was 6d. per fleece, which was raised to 2s. per fleece by an Act of George III.

Many years ago these Acts were repealed, along with some others which were obsolete. So ingrained had become the custom of getting the wool up in the most desirable manner, and there was so little trouble arising upon this head, that the wool trade allowed the Acts to be repealed without a murmur, and the custom since their abolition has been for all practical purposes precisely what it was before. Accidents will always happen; there will always be some careless shepherds; and probably there will always be some growers who cannot resist the temptation of selling dirt at the price of wool, but the general bulk of wool-growers have hitherto produced their wool for sale in a creditable manner, and in a manner which is the only one that can be described as the "custom of the trade."

During recent years, however, a new spirit appears to have been creeping in, and practices have been indulged in which have resulted in friction, and sometimes law.

Some of these practices must be put down to the unfortunate anti-sheepwashing agitation which was got up some years ago, and which, although emphatically condemned by the trade, has left behind it a legacy of trouble.

Another cause is probably to be found in the long continuance of low prices. It is asked by some farmers, "What is the use of our taking so much pains upon an article for which we get so little money?"

This kind of argument produces a feeling of despair in the mind of the trader in domestic wool. Low prices are by no means confined to the wool trade. But in other trades both producer and customer are looking around in every direction for any likely means of improving the commodity, and are trying to help each other in working them out. In the wool trade, however, the new school seem to be saying, "Prices are very low; let us, therefore, deliver the wool in worse condition, and so recoup ourselves." And so instead of their helping to fight the ever-increasing competition, we have the singular spectacle of the producers of an article doing their best to hamper and inconvenience the other branches of the trade.

It is well to keep in mind the state of affairs as regards competition in wool. Leaving out the mountain wool, such as Scotch black-faced, which has a market of its own, and reducing all the wool to the absolutely clean or scoured state for purposes of comparison, the following is the production of competing wool:—

United Kingdom	90,000,000 lbs.
Australasia and River Plate .	262,000,000 lbs.

Mutton is now the dominant factor in the wool trade, and is transforming our long-woolled flocks at home into half-bred. In the Colonies and in the River Plate mutton has given a fresh impetus to the growth of similar wool. What is more, the promise of future increase in this direction appears to be boundless.

In 1898 the Argentina alone bought 6632 stud sheep from this country, at a cost of £94,323, and in the imports from that country may be found wool which will compete with almost any class grown in the British Isles.

When to this it is added that almost everything is done by the grower abroad to make his wool acceptable in the eyes of the European consumer, it does seem the height of folly that we should, by our own slipshod work, be doing our best to give the importers another point or two in the competition.

This is essentially a farmers' question, for it cannot be too clearly understood that the user will soon tire of it. If the practices complained of become general, and the grower insists upon treating his wool as a bye-product which is not worth any care, the inevitable result must be that the British manufacturer will give increased attention to the vast quantity and choice of imported wools, which are free from the faults complained of, and in which business is so easy to manage. The trader asks for nothing new or arduous. All he requires is an honest adherence to the best traditions of the past, if he is to do his share in preserving the past pre-eminence of the native product.

To do this the trader expects the grower to observe the following points:—

(1) The sheep should not be allowed to run too long after washing before being clipped, as this means in effect getting the wool back into greasy condition.

(2) Nor should they be clipped while wet, as this takes away the liveliness from the fibre and causes the wool to rot.

(3) They should not be clipped in dirty places, such as barns littered with chaff and straw and other matters which get into the staple and cause endless trouble and annoyance. The cost of this fault to the user is serious, as it is often impossible to get this foreign matter out without the use of chemicals.

(4) When the fleece is wound, no clags of earth or dung should be left on the fleece, nor put in whilst winding.

(5) No locks, tailings, skin wool, black, or cots should be wrapped up inside fleeces, nor greasy wool wrapped up inside washed fleeces.

(6) The fleeces should be tied up with bands made by twisting a portion of the fleece itself. Strings composed of vegetable matter, such as hemp, jute, etc., are bad, and ought not to be used.

The most careful manipulation by the manufacturer often fails to detect small pieces of string, which do not make their appearance until the cloth is dyed, because the dyes which are required for wool will not do for vegetable matter. Pieces of cloth are often damaged in this way to a very aggravating extent.

All the farmers of the United Kingdom can tie up their fleeces with wool bands, and have done so for generations, with the exception of a few western and southern counties. In the latter there is not only a perverse adherence to the use of string generally, but an amount of ingenuity in using the worst kind of string for the purpose—such, for instance, as reaper or binder twine—which in any other trade would be called wanton mischief.

Even our great competitors at the River Plate have opened their eyes to this evil, and they do not forget to advertise the public that their wool is thoroughly skirted and without strings.

In round figures, the total average production of wool in the United Kingdom for many years has been 138,000,000 lbs. per annum. The amount of this exported has been 20,000,000 lbs. per annum.

Probably not one bale of this wool could have been exported unless it had fulfilled the conditions specified above. Our best customer is the United States of America, whose manufacturers cannot afford to pay 5½d. per lb. duty on dirt and dung, and whose labour is too costly to be wasted on picking out chaff and strings.

One satisfactory outcome of the discussion is that the auctioneers of wool have met the Wool Trade Committee, and have agreed with them upon a definition of what constitutes "unfair packing." A large quantity of our clip is now sold by auction, and it is obvious that in these cases a thorough examination of the insides of the fleeces would simply stop business. The wool has hitherto been bought, therefore, on the well-known basis of condition which has so long been the custom of the trade. By the new conditions of sale the auctioneers will reserve the right to make allowances to the purchaser for any damage arising from such practices as are condemned in articles 4 and 5 of the Wool Committee's Report.

Vegetable Matter in Wool

An influential meeting of Australian and New Zealand wool-growers, British and Continental consumers and wool-brokers, was held in London on October 2, 1907, to

consider complaints from the manufacturing users of wool in Europe and America of the presence of vegetable fibres in wool imported from Australasia and other wool-growing countries, and if possible to devise means to remedy the evil.

The nature of the evil was explained. Small bits of bagging and string became mixed up with the wool, and though the utmost care be taken in the "sorting" to pick these out, some of them pass with the wool through the washing process, and so through the combing, spinning, and weaving, because these fibres are then quite indistinguishable by the naked eye. When the manufactured cloth comes to be dyed, the presence of these vegetable fibres instantly declares itself, because wool being an animal fibre "takes the dye," while these vegetable fibres remain white, or nearly so. Such goods are imperfect, and in that condition quite unmerchantable. Often there is not a single yard of the cloth without its blemish, as some dyes used for vegetable substances, as cotton, linen, are not suited for wool, and conversely.

To remove these defects is an exceedingly slow, laborious, and costly process. Every such fibre must be patiently picked out of the woven piece by the deft fingers of the "burler," it being impossible to detect the jute fibres in any previous operation. The utmost care must be used not to injure the cloth. It is an operation most trying to the eyes and calling for great skill. Some firms pay many thousands of pounds annually in wages to "burlers," as the women are called who do this work. If these fibres could be kept out of the wool in the first instance, this heavy annual tax upon the industry would almost cease.

If the manufacturer who suffers in this way were himself the purchaser of the wool, he would undoubtedly long

since have found a remedy by enforcing reform. But the trade is now so specialised that it would be impossible to trace back the wool to its source. The buying agent, the topmaker or importer, the comber, the spinner, all handle and blend and mix the wool before it comes into the hands of the manufacturer as yarn. Even manufacturers who perform all the operations themselves cannot escape, and, as explained above, the defects are not visible until the mischief is done. Hence the absolute necessity for dealing with the evil so that it may be attacked at its source.

How the Mischief is caused

Vegetable substances which are found at various times, under varying conditions and in greatly varying quantities, may be divided into two classes:—

1. Vegetable substances in their natural state, such as burrs, grass seeds, thorns.
2. Vegetable fibres in more or less artificial association.

With regard to the first class, it may be stated that many ingenious and costly mechanical devices have been invented to get rid of these things. The Yorkshire Wool-combers' Association, Limited, paid £60,000 to a French syndicate for the English patent rights of a process for de-burring wool; and many times this sum has been spent in the same quest. The most effective way is to "carbonise" or "extract" such substances by the use of acids. This, however, inevitably injures and deteriorates the wool fibre itself. In practice it is only applied to such wools as are "full of burr" or seed. It is a process not to be seriously contemplated in connection with the better class of wools—the combing wools which fetch the highest

prices—hence the great pains and cost incurred to get rid of these substances by mechanical means.

The second class of fibres find their way into the wool by man's assistance. They are equally, nay, even more detrimental and more difficult to eliminate. They are usually either jute, hemp, or cotton. They are found as

Pieces of bagging.

Pieces of rope or twine used in tying fleeces.

Pieces of sewing twine.

Shreds of bagging, twine, etc., more or less abraded, which have been gathered up from the floor of the shearing shed, the warehouse, or the quayside with wool which has been pulled out for sampling or has escaped through damage to the tare.

These fibres are more difficult to deal with, because—

They are often too minute to be seen except by the aid of a magnifying glass;

They are, especially if unravelled, often not unlike greasy or dirty wool in colour;

They are frequently so numerous and so distributed over the surface of the wool when the bale is first opened that it would be practically impossible, at whatever cost of time or labour, to pick them all out;

When, after the wool has been "sorted," it goes through the process of washing, the fibres become softened, detached one from another, and are bleached as white as the wool itself, so that they cannot again in any subsequent process be readily detected by the eye;

Being straight, fine fibres they behave like the wool fibres, and are ultimately spun into yarn with the wool.

The most careful investigation has shown that the great bulk of the mischief is traceable directly or indirectly to the unsuitable character of the wool-pack in common use in the colonies.

This pack is of jute, and the quality has steadily deteriorated for many years. But the deterioration has been more pronounced since the price of jute began to advance. A shorter fibre is now used, and the bagging is not so hard or "clean" as it used to be—it is more "fuzzy." If a new pack be rubbed against the sleeve of a dark cloth coat, it will at once be seen that a number of fibres have come off the bag and are sticking to the coat. When a bale of wool is opened it is found that the surface of the wool which for three, six, or nine months has been in close contact with the tare is frequently covered with thousands of such particles of jute fibre.

Whenever and wherever the pack is cut the material of which it is made frays, little bits come off, and stick to the wool.

Remedies for the Evil

First and foremost the general adoption of a wool-pack of such a character that it will not depreciate the value of the wool it contains. The committee are pursuing inquiries in regard to the provision of a better bag. They hope shortly to be able to give further information and to recommend an improved wool-pack and sewing tw[illegible] r general use.

The adoption of such a standard pack, made [illegible] ed, clean, hard twisted jute or hemp yarn, carefull[illegible] so that the pack does not need to be "cut down [illegible] the corners in the baling press, and provided with a [illegible] rate

piece of canvas for the top of the bale, would do a vast deal to mitigate the evil.

The systematic emptying of the pack before it is put into the press. It is found that frequently bits of the canvas and the ends of sewing twine come inside the new packs from the factory. Care should be taken to see that these are shaken out.

In the shearing shed, in the classing and packing of wool, the utmost care should be used to prevent loose bits of twine, rope, or bagging coming near the wool, or being swept up with wool from the floor.

The tying of fleeces ought to be avoided entirely.

All straw, etc., should be carefully removed from the shearing place before shearing commences.

In stores and warehouses where bales are exposed for sampling, the necessary opening of the tare should be done so as to damage it as little as possible. Bales should be opened at the seams by cutting the sewing twine; and all the frayed edges and loose bits should be removed and destroyed.

It is recommended that printed cards should be provided for hanging in shearing sheds and warehouses in the following terms:—

For Shearing Sheds

1. All straw, etc., should be carefully removed from the shearing shed before actual shearing is begun.
2. Turn out each bag before packing the wool, and see that it is clean and free from bits of hemp.
3. Loose bits of twine, bagging, or straw should be carefully kept apart from the wool.

For Warehouses

1. All bales must be opened at the seams only by cutting the twine.
2. Any frayed edges or loose pieces of string should be removed carefully and at once by men whose special care it is to watch the wools when "on show."
3. Warehouse "pullings" should be carefully looked over before being restored to the bales.

CHAPTER IX

MECHANICAL STRUCTURE OF THE WOOL FIBRE

It has been seen that the difference between wool and hair is rather one of *degree* than *kind*, and that all the wool-bearing animals have the tendency, when their cultivation is neglected, to produce hair rather than wool. This tendency also always manifests itself whenever the conditions of soil and climate are unfavourable to the fullest development of the animal.

Difference between Hair and Wool.—There is indeed great difficulty in giving any real definition which will exactly cover the difference between wool and hair. They have almost identically the same chemical composition, and to the unpractised eye they are almost equally difficult to distinguish by their mechanical structure, because the fine hair in some animals is very like wool, and the coarse wool on others closely resembles hair. The softness and pliability which is so remarkable in some wools is absent in others, and some true hairs are quite as soft and silky. The very fineness of the fibre cannot in the same way be relied on, as we have true wools which range from the very finest fibres of the Saxon Merino up to the longest locks off the flanks of

the Lincoln ram, which are as coarse and thick in diameter as any of the hair-bearing goats. In the same way even the curl in the lock, which is perhaps the best general and rough distinction between wool and hair, is found to pertain in some true hairs if we are to take the method of attachment of the epidermal scales of the fibre as any fixed guide. Colour and degree of transparency also cannot be relied upon, as we have as great variety in hair as in wool, and even the lustre is apt to deceive, because we have an almost metallic lustre in both. The Mohair is a true wool, if we are to take the arrangement of the scales as a guide, and the Alpaca wool is much nearer allied to true hair, and indeed many of the fibres are such, and yet both are distinguished by their high lustre.

Shedding of Hair.—Some writers have endeavoured to distinguish between wool and hair by the periodical decidence or falling off of the latter, which appears to be much more regular and periodical than the former. We see this in the case of the horse and cow; and this periodical shedding is much more marked in the case of the animals in their wild state than when they are domesticated. When under domestication many of these changes are modified, and in the case of man at any rate there is no periodical falling off of the hair. When in a wild state, or in the more neglected breeds of sheep, there is no doubt a periodical moulting or separation of the old pelt or fleece from the growth of new wool beneath, and at the commencement of summer this would gradually be thrown off if the sheep was not shorn, but in the more cultivated breeds this tendency is much less marked, and in some cases so entirely disappears that the wool will continue to grow from season to season. The reason is

probably this: when under natural conditions the sheep is much more exposed to the effects of the different seasons of the year, both in regard to the inclemency of the weather, and more than all the scarcity of food, and this produces a marked effect on the strength and thickness of the wool fibre. When the winter season is over, and abundance of food becomes again possible, the wool increases in strength and shedding occurs, the fibre separating at the weak places. Indeed, amongst some savage races this knowledge that starvation produced a deterioration of the fibre was turned to account, before the introduction of shearing, as a means of obtaining the fleece from the sheep. The animals were confined without food for some days until a short growth of weak and debilitated hair had been produced, and thus the fleece could readily be torn from the surface of the skin.

This definition of wool and hair, however, cannot be accepted as really distinctive, as there are numerous exceptions amongst animals which bear both fibres. Although no definition of the difference between them is quite possible, those who are accustomed to work amongst wool have no difficulty practically in telling the difference.

The true distinction between wool and hair, indeed, seems to be principally in the way in which the scales on the surface of the fibre are attached to the body of the fibre, or rather to the cellular mass of the fibre which lies immediately beneath them, and we can best understand this by dealing with the first division of our subject, viz.:—

I.—*What is the typical structure of a wool fibre?*

To answer this question it is necessary to look at it in a twofold aspect.

A. In regard to the mechanical arrangement of its ultimate parts.

B. In regard to its chemical composition.

Structure of Wool.—A. Wool and hair are simply modifications of the same epidermal excrescence, and we have already almost anticipated what can be said definitely in regard to the typical structure of the wool fibre in Chapter IV. There we saw that the fibre of true wool is always covered with numerous lorications or scales, the upper extremity of which are pointed rather than rounded in form, and which may be seen distinctly in the fibre delineated in Fig. 15. The scales also have a much larger free margin than in the case of hair, being only attached for about one-third of their length, and in many cases the free ends are more or less turned outwards, so that they present a much more serrated or denticulated edge. The interior portion of the fibre, however, differs in no respect from hair, and cannot be distinguished from it, as there are many wools which differ in regard to the central part in the form of the nucleated cells just in the same way that different hairs do. We shall afterwards see, when we come to another part of our subject, that there is a very wide difference in the structure of different wools in regard to the nature of the scales and their distribution on the surface of the fibre, and also in regard to their number and strength. We shall also find that the structure of the fibres taken from different parts of even the same animal exhibits different modifications both in regard to the thickness and length of the fibre as well as its surface covering. The wool fibre is a long cylindrical structure, which varies in length and diameter in different breeds of sheep. In some it is only an inch or thereabouts in length, and in others extends to a yard or more, while

the variation in diameter is from $\frac{1}{3500}$th of an inch in the finest Saxony to $\frac{1}{50}$th of an inch in the coarsest part of some of the deep-grown English and foreign wools. We shall look at this variation more particularly farther on. In the first growths of the wool, as is the case before shearing, the fibre has a more or less tapered form, and terminates with a pointed or rounded end. After shearing, as in wether fleeces, however, the thickness is more or less uniform from end to end, but still irregular, as the health of the animal and the conditions under which it is placed have a considerable effect in this direction.

In looking at one of the best types of wool fibre we are struck with the beauty of the whole arrangement, by means of which lightness and strength, as well as pliability and brilliancy of surface are secured. This beauty of structure is wonderfully revealed when we carefully examine the cross section of a hair, as exhibited in Fig. 8.

In the central portion of the structure we have a strong cellular axis, which is usually composed of rather larger cells than those which immediately surround it. All round the cellular axis the mass of elongated cells, which form the bulk of the fibre, are arranged in compact regularly distributed masses, usually appearing to increase rather in size, and diminish somewhat in density, till we reach the scaly part or outer margin of the fibre. The closer arrangement of the fibres surrounding the central cells, and which forms the cortical substance of the hair or wool, enables the fibre to stand the crushing action which is always present when a cylindrical structure of any appreciable diameter is subject to flexure, and the larger cells and less dense arrangement on the outer surface render those parts more elastic, and therefore better able to withstand

the flexure which they must undergo when extended or compressed by the same action. The section of a wool fibre differs from that of a hair in having much less frequently a development of the central cells, so that in well-grown and true-bred white wool the cells forming the cortical structure consist of cells with transparent laminated walls and hardly any trace of a nucleus,—indeed, even when acted upon by alkalis so as to dis-

FIG. 47.—Transverse Section of Wool Fibre (Lincoln Hog).
× 450 diameters.

Showing the closely packed transparent cells with outer sheath of epidermal scales.

integrate the cells from each other, they have the appearance of transparent jelly-like elliptical bodies, which vary in length from $\frac{1}{400}$th to $\frac{1}{700}$th of an inch, and in diameter from $\frac{1}{1500}$th to $\frac{1}{2000}$th of an inch. It is probable that when thus treated and separated from each other these cells are enlarged or swollen more than when arranged within the fibre. The appearance of a cross section of a wool fibre is something like what is represented in Fig. 47, where it will be seen that the cells are smaller and less

marked than in the hair section. The arrangement of scales upon the surface, the free margins of which can slide over each other, secure the greatest amount of liberty to the surface of the fibre, without any rupture of the covering, which would undoubtedly be caused by any more rigid arrangement of the epidermal part. The greater softness and pliability of the wool fibre, as compared with the hair where the free margins are less, is a striking proof of the value of this arrangement.

This peculiarity of the structure of the wool fibre has been known for a considerable length of time, although its importance and the exact nature of all the peculiarities which it exhibits have only been the subject of careful examination within comparatively recent years.

History of Structure.—As early as 1664 Dr. Hooke read a paper before the Royal Society upon the structure of various hairs, but the microscopic power at his command was only limited, and the observations consequently very incorrect. He considered the substance of hairs to be solid. About the year 1690 Leeuwenhoek turned his attention to hairs and wool; but although he figures in his works several specimens, they are not correct, probably because of defective instruments for examination, as he was a most careful observer. About the year 1742 Henry Baker, F.R.S., read a paper on the subject before the Royal Society, but little advance was made until the invention of the compound microscope and its improvement at the beginning of this century. Mr. Youatt, whose work on sheep has already been mentioned, claims to have been the first person who really discovered the true nature of the surface of the wool fibre. We give it in his own words: "On the evening of the 7th February 1835, Mr. Thomas Plint, woollen manufacturer,

Leeds; Mr. Symonds, cloth agent, of London; Mr. T. Millington, surgeon, of London, an esteemed friend; Mr. Edward Braby, veterinary surgeon, at that time assisting the author in his practice; Mr. W. H. Coates, of Leeds, veterinary pupil; Mr. Powell, the maker of the microscope; and the author himself, were assembled in his parlour. The instrument was, in Mr. Powell's opinion, the best he had ever made. A fibre was taken from a Merino fleece of three years' growth. The animal was bred by, and belonging to Lord Western. It was taken without selection, and placed on the frame to be examined as a transparent object. The power 300 diameters was used, and the lamp was of the common flat-wicked kind. The focus was readily found, as there was no trouble in the adjustment of the microscope, and, after Mr. Powell, Mr. Plint had the most perfect ocular demonstration of the irregularities in the surface of wool, the palpable proof of the cause of one of its most valuable properties—the disposition to felt. The fibre assumed a flattened, ribbon-like form. It was of a pearly-grey colour, darker towards the centre, and with faint lines across it. The edges were evidently hooked, or, more properly, serrated; they resembled the teeth of a fine saw." When examined as an opaque object with a view to determine the cause of this serration, "we were presented with a beautiful glittering column, with lines of division across it, in number and distance corresponding with the serrations that we had observed in the fibre that had been observed as a transparent object. These were not so marked as the inverted cones which the bat's wool presented, but they were distinct enough; and the apex of the superior one, yet comparatively diminished in bulk, was received into the excavated base of the one immediately beneath, while the

edge of this base, formed into a cup-like shape, projected, and had a serrated or indented edge, bearing no indistinct resemblance to the ancient crown. All these projecting indented edges pointed in a direction from root to point."

The illustrations which are given in Mr. Youatt's work of the microscopical characters of various wools are most certainly the best which had been given up to that time, although in some respects they evidently exhibit a wider difference in allied wools than is found in the average fibres. Since then, however, much better illustrations have been given in various works on wool, such as Dr. Lankester's lectures at South Kensington Museum, various treatises on the microscope by Dr. Carpenter, Dr. Hogg, and others, and especially in the *Micrographic Dictionary*. Most of these illustrations, however, are only drawn with low powers, and mostly apply to "wool in general" rather than "wools in particular."

Scales on Wool.—When we examine a fibre of fine lustre wool as an opaque object under the microscope, it forms a most beautiful picture. If the surface has been thoroughly cleaned, so as to remove all the natural grease from the surface, it appears, when the light is properly thrown upon it, like a laminated surface of silver. The scales have an almost transparent look, and a smooth, lustrous brightness, which well accounts for their excellent reflecting properties. Before preparation, and in the natural condition as the wool grows upon the back of the sheep, the scales, covered as they are by the natural oil, adhere more or less to the shaft of the fibre, and their transparency and thin edges, especially in the finer classes of wool, render them almost invisible, except as fine anastomosing lines across the diameter of

the fibre. When the wool is, however, treated to remove the grease by boiling in weak caustic alkali, the scales become more or less loosened from the surface, and we can then see their arrangement more distinctly, and the method in which their attachment differs from that of hair. When powerful microscopical power is used the surface of the scales is found to present a more or less reticulated or pitted appearance, which is much increased by the continued application of the hot alkali. This is the cause why too much washing injures the lustre of the wool. The action of the soap and hot water upon the surface of these fine scales destroys the continuity of the reflecting surface, and causes it, like any rough surface, to disperse the light instead of reflecting it in solid sheets. The property of lustre in all wools is indeed one of degree, and is much more dependent upon the character of the surface of the individual scales upon which light falls than upon either their number or arrangement. As a rule, however, in the case of wool a fewer number of scales is accompanied by an increase in lustre, because the reflecting surfaces become larger; but in some cases, as we shall afterwards see, and especially in the coarser variety of wools, the larger surfaces of the scales are accompanied by an increased roughness in the texture of the scales, and thus the dispersion is increased in this way to a greater degree than is compensated for by the larger surface.

When the scales themselves are carefully studied under a variety of different illuminations, it is found that they present considerable differences in regard to their thickness and transparency. In the case of some wools the scales have almost the density and texture of ivory, which, indeed, they closely resemble; while in

others they have the appearance of opal glass, and we can easily detect the reflection of the light both from the upper and under surface. When the scales are very thin and transparent we have also frequently the production of iridescence or coloured fringes to the margins of the scales, which give them almost the appearance of mother-of-pearl. These fringes are, however, too small to affect the general character of the light which is reflected from the surface. The transparency of the hair and its colour is largely dependent upon the mechanical arrangement of the cells within the cortical part, and when this is disturbed both are altered. It is well known that if a white transparent horse-hair is stretched beyond a certain point it will obtain a permanent set, become suddenly opaque, and of a bluish-green colour, and very brittle. This probably arises from the rupture of the surfaces of the cells from each other, which breaks the optical continuity of the cortical substance. While the effect produced upon the light by the mechanical arrangement and structure of the surface of the wool is to a large extent the cause of the lustre, there is no doubt but that the chemical composition and nature of the individual scales, as well as of the immediate surface, is also important, because a very small change, occasioned by the action of various reagents upon them, has a very great effect upon this property of reflecting light. Nor is the immediate surface of the wool all that is concerned in the production of a lustrous appearance, because in the case of many wools which have perfectly transparent and lustrous surfaces, this is modified by the structure of the cortical part of the wool, and more especially by the existence of pigment cells, which form more or less dispersive points, and so tend to modify the general appearance of the reflection

from the surface. In some cases these pigment cells only tend to increase the lustre, especially when the light is falling at certain angles, because they return the rays which would otherwise have passed through the more transparent fibre. The colour of these pigment cells also has something to do with the brilliancy, because some colours naturally reflect more light than others. This is not, however, of much importance to us as technologists, because there are very few coloured wools which are used in their natural condition, as they are seldom employed except into fabrics which have to be artificially dyed, and it is therefore of more importance to know how these naturally coloured fibres deport themselves in regard to dyeing materials than in regard to light before dyeing.

Cortical Structure.—Just as there is a considerable difference in the number and size of the scales or flattened cells with which the surface of the wool fibre is covered in different breeds of sheep, there is also a difference in the mechanical structure of the cortical part of the fibre. In some wools these cells are considerably larger than in others, and the cells themselves, when subjected to the action of reagents, present different appearances so far as the relation between diameter and length are concerned, as well as the thickness of the cell-walls. These walls themselves appear to consist of more or less concentric rings of transparent matter, which vary in thickness from $\frac{1}{5000}$th of an inch to a degree of tenuity which exceeds the power of measurement. As in the case of the cotton fibre, however, it is not possible by any microscopical power at command to distinguish the texture of the ultimate layers of which these cells are composed, and which, so far as can be judged, seems to be a continuous membrane, which is, however, capable of permitting the

passage of liquids through it, and thus acts as a dialyser. Although the cells are closely packed together and do not seem to have any perfectly regular or systematic arrangement, they are attached at their outer surfaces in such a way as to withstand an immense strain, as we shall afterwards see when considering the power to resist tension in the different classes of wool. When subjected to tension, however, the surfaces seem to be able to slide over each other, the cell-walls become more attenuated, and the nuclei more elongated, so that the whole cell is drawn out and the diameter of the fibre becomes less. If the tension is continued till fracture occurs, it seems generally to take place at the point of junction of the various cells, and not by the rupture of the cells themselves. In all cases after the fracture of a fibre where subjected to the action of reagents which showed the individual cells, it was not possible to detect in any case that the cells themselves were fractured. They seemed to have pulled out from amongst each other, and the spindle-shaped ends of the cells, where they had interlocked, were still visible, protruding from the fractured surface. When examined under the microscope the method of fracture of a wool fibre differs entirely from that of cotton. In the latter, the fibre being a hollow tube, collapses, and then usually fractures at one edge first; but the more solid and complicated wool fibre resists the strain more equally and fractures along the weakest part of the fibre at the junction of the scales, which appear as if torn out of the sockets. All fibres when closely examined are found to vary considerably in the diameter of the different parts, and although the fibre usually breaks at the thinnest part, it is by no means universal, as some parts of the fibre which are large in diameter

are sometimes apparently softer in texture, or at any rate less rigid to resist longitudinal strains.

Strength of Fibres.—In order to determine the strength of the fibres of various kinds of wool, the author got a machine constructed on the principle of the steelyard, so that he could measure the limit of the elasticity of the fibres as well as the breaking weight. Fig. 48 gives a good illustration of this machine.

A is a base board of mahogany upon which is fixed a pillar, B. The top end is forked into a jaw, carrying

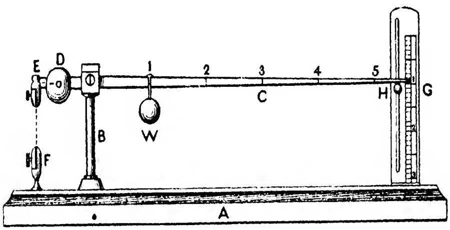


FIG. 48.—Single Fibre Testing Machine. Scale 1½ inch = 1 foot.

on each side a screwed centrepiece, into which is fixed the fulcrum of the lever E C H. These two centrepieces can be screwed closer together, or further apart, as required, and the pivot which forms the fulcrum of the lever is pointed at each end, and fits into a hollow in the two ends of the centrepieces, so that it works perfectly free, and yet can have no lateral motion, as would be the case if knife-edges were used. The lever, C, is divided into five equal parts, each of which are equal to the distance of the centre of the jaw, E, from the centre of the fulcrum. D is a balance weight to counterpoise the longer arm of the lever, C. Each of the five divisions of the lever,

C, are divided into ten parts. The range of the instrument depends upon the weight of the sliding weight, W, and this can be varied at pleasure. Three different weights, were used, viz. 50 grains, 100 grains, and 1000 grains, and the range of the instrument with these different weights was therefore as follows:—

Weight.	First Division.	Second Division.	Third Division.	Fourth Division.	Fifth Division.
Grs.	Grs.	Grs.	Grs.	Grs.	Grs.
50	50	100	150	200	250
100	100	200	300	400	500
1000	1000	2000	3000	4000	5000

By using the intermediate decimal divisions of spaces on the lever, we obtain, in the case of the 50-grain weight, an increase of 5 grains for each division; with the 100-grain weight, 10 grains for each division; and with the 1000-grain weight, 100 grains for each division; and a little practice with the instrument enabled half of these divisions to be easily used, so that the range was from 50 grains up to 5000 grains, with difference of not less than 2·5 grains when the 50-grain weight was used, 5 grains when the 100-grain weight was used, and 50 grains when the 1000-grain weight was used.

At the end of the lever, C, a graduated scale, G, was placed, divided into spaces which enabled the elasticity of the fibre to be measured in terms of the distance of the two jaws, E and F, from each other. This distance was fixed at two inches. A separation of the jaws to the extent of one-tenth of an inch marked half an inch on the scale, and thus enabled very small ranges of elasticity to be readily seen. A small stop, which could be adjusted by a thumbscrew at the back of the plate, was inserted in a long

slot in the divided plate, so as to prevent the fall of the lever when the point of fracture was reached. When the machine was used, the fibres to be tested were fastened into the two jaws, E and F, by relaxing the small set-screws at the side and opening the space between the two planes of which each jaw is composed. The length of the fibre between the two jaws was roughly adjusted until the pointer at the end of the lever arm pointed to 1 on the scale, G. A trial was then made of a number of the fibres under examination, so as to judge roughly of the elasticity and breaking weight. When this was ascertained a series of fibres were selected, and the adjustment between the jaws made as accurate as possible. The weight necessary to fracture the fibre, which had previously been roughly ascertained, was then accurately determined, as the rough adjustment had enabled the necessary weight and part of the lever on which it was necessary to place it to be ascertained, and thus much time was saved. When moving the weight along the arm in the final experiments, a fine silk thread was used to raise it with, attached to the ring which slid along the lever, and thus any pressure from the fingers, either horizontal or vertical, was avoided. In making the experiments, it was found that very few fibres were equally sound throughout,—that is to say, that if, when the fibres were long enough, two inches were taken at one end, then two inches or multiple of this number from the middle of the fibre, and then the same quantity from the other end, that there was considerable variation in the breaking weight as well as the elasticity in each of these separate two-inch lengths. Both these qualities depend on the weakest part of the fibre, and some fibres fractured almost at once and exhibited little elasticity. In the tables which follow, however, the soundest and most uniform

fibres which occurred in the lock were taken, and when this was done there was found to be a considerable degree of uniformity both in the breaking strain and in the elasticity. It was found also that both these qualities were considerably affected by the hygroscopic state of the fibre, and so as to ensure a uniform comparison, all the locks of wool to be experimented upon were kept in a uniform temperature of 60° to 65° F., and all were taken from locks of wool out of the fleece unscoured, and therefore containing the natural fats within the fibre. In measuring the diameters of the fibre before and after breaking, a series of experiments were made on the diminution in diameter when the fibre was subjected to strain without breaking, so as to find out at what proportion of the breaking strain the fibre obtained a permanent set. Up to a certain point the fibre, when released from strain, regains its diameter by the shrinking in of the cells, but after a certain point it ceases to do this. Few fibres of any of the wools stretched equally along the whole extent of the fibre, but when subjected to strain disclosed thin and thick places, that is, lengths of greater and less elasticity, and the measurements of these were taken and averaged, after the fibre was broken, in the same way that the diameter was averaged when measuring previous to breaking, and before putting into the jaws of the machine.

The following tables give the result of these experiments:—

[TABLE

Kind of Wool.	Breaking Strain in Grains.	Elasticity in Percentage of Length.	Diameter of Fibre before breaking in Decimals of an Inch.	Diameter of Fibre after breaking in Decimals of an Inch.	Difference in Decimals of an Inch.
Human Hair	1680	·374	·00342	·00283	·00059
	1750	·356	·00353	·00275	·00078
	1436	·389	·00301	·00241	·00060
	1620	·343	·00325	·00270	·00055
	1720	·371	·00342	·00283	·00059
Average	1641	·366	·00332	·00270	·00062
Lincoln Wool	580	·210	·00185	·00161	·00024
	420	·288	·00173	·00152	·00021
	510	·313	·00196	·00167	·00029
	533	·310	·00188	·00166	·00022
	465	·270	·00165	·00150	·00015
Average	502	·281	·00181	·00159	·00022
Leicester Wool	180	·240	·00175	·00131	·00044
	455	·275	·00143	·00122	·00021
	500	·300	·00182	·00158	·00024
	422	·280	·00163	·00141	·00022
	510	·270	·00158	·00138	·00020
Average	473	·273	·00164	·00138	·00026
Northumberland Wool	420	·224	·00143	·00120	·00023
	330	·310	·00161	·00124	·00038
	540	·265	·00148	·00132	·00016
	418	·250	·00136	·00118	·00018
	440	·300	·00155	·00132	·00023
Average	429	·270	·00149	·00125	·00024
Southdown Wool	82	·230	·00101	·00090	·00011
	75	·320	·00094	·00081	·00013
	93	·200	·00083	·00071	·00012
	102	·380	·00121	·00080	·00041
	80	·210	·00097	·00082	·00015
Average	86	·268	·00099	·00081	·00018

Kind of Wool.	Breaking Strain in Grains.	Elasticity in Percentage of Length.	Diameter of Fibre before breaking in Decimals of an Inch.	Diameter of Fibre after breaking in Decimals of an Inch.	Difference in Decimals of an Inch.
Australian Merino	48	·387	·000510	·000354	·000186
	63	·421	·000583	·000332	·000251
	43	·334	·000471	·000320	·000151
	50	·283	·000521	·000391	·000130
	46	·251	·000472	·000361	·000111
Average	50	·335	·000517	·000351	·000166
Saxony Merino	43	·321	·000317	·000210	·000107
	38	·284	·000321	·000220	·000101
	36	·253	·000340	·000230	·000110
	40	·241	·000381	·000246	·000135
	37	·263	·000331	·000213	·000118
Average	39	·272	·000338	·000224	·000114
Mohair	600	·285	·00174	·00132	·00042
	540	·310	·00158	·00141	·00017
	580	·300	·00163	·00136	·00027
	620	·294	·00178	·00141	·00037
	590	·306	·00180	·00142	·00038
Average	586	·299	·00170	·00138	·00032
Alpaca	150	·231	·000521	·000387	·000134
	162	·213	·000562	·000441	·000121
	144	·265	·000493	·000366	·000127
	153	·250	·000546	·000112	·000131
	138	·220	·000511	·000402	·000109
Average	149	·242	·000526	·000401	·000125

In looking at the figures given in this table, it will be seen that the strength of the fibres generally follows the diameter,—that is to say, that the fibres having the largest diameter, and, therefore, largest cross section, carry the greatest weight, and if these diameters are compared with

those given in the author's work on the *Structure of the Cotton Fibre*,[1] and then with the breaking strain of the fibres of the various classes of cotton given in the same work, it will be seen how much stronger the animal fibres are, in comparison to their diameters, than the vegetable fibres. For example, the fibres of Egyptian cotton average ·000655 of an inch in diameter, which is about $\frac{1}{1526}$th of an inch, and these carry a breaking weight of about 127·2 grains. This is just about double the diameter of the Saxony merino fibre, which has an average diameter of ·000338, or $\frac{1}{2958}$th of an inch. Indeed, one of the fibres given in the table, viz. the second of the fibres, is almost exactly half, being ·000321 of an inch, as against ·000327 of an inch in the cotton fibre, and this particular fibre had a breaking strain of 38 grains, as against 127·2 in the cotton fibre. Assuming the breaking strain of the two fibres to be directly as the areas of the two fibres, it should vary directly as the squares of the diameters, and hence the wool fibre, if as large in section as the cotton fibre, would carry 158 grains, since the area of the cross section of the cotton fibre is 4·16 times the area of the wool fibre. If the areas of the two fibres were equal, the wool fibre would be fully 25 per cent stronger. The cause of this is, probably, the fact that while in the case of the cotton fibre, which is a hollow tube, and when subjected to strain is apt to collapse, and then rupture at the edges of the ribbon which is formed by the collapsed tube, the interior of the wool fibre is much more filled up with regularly disposed cells, which tend to give the epidermal sheath of the wool fibre considerable support by preserving its circular form, and thus distributing the strain more regularly over the whole area. To set against this, how-

[1] *Structure of the Cotton Fibre*, page 264, Macmillan & Co. 1908.

ever, there is the fact that the layers of which the cotton fibre is built up, while concentric, are continuous throughout the length of the fibre, while the cells composing the cortical and epidermal part of the wool fibre are not continuous, which introduces a great source of weakness, as we have already seen, as it is always at the junctions of cells in the transverse direction that fracture occurs. There is such variation in the strength of fibres from different wools off the same class of sheep, that, like the variation in diameter, we can only consider these tables to give approximate results, but they will serve to give a general idea of the strengths and elasticities of the different varieties, and were the result of great labour and care.

It is interesting to compare the figures of tensile strength for equal cross section of fibres. As the cross section varies with the square of the diameter, by taking the ratio of these numbers and multiplying by the tensile strength, a figure is obtained which represents the tensile strength for equal diameters.

In this manner the following table has been calculated, taking the human hair, which has the largest diameter, as the standard at 100:—

TABLE OF RELATIVE STRENGTH OF FIBRES

Human Hair	100·0
Lincoln Wool	96·4
Leicester Wool	119·9
Northumberland Wool	130·9
Southdown Wool	62·3
Australian Merino Wool	122·8
Saxony Wool	224·6
Mohair	136·2
Alpaca	358·5
Cotton (Egyptian)	201·8

Examining the relative strengths of wool fibres in the same way as above, and taking Southdown wool as the standard for the 100, since, on the average, fibres derived from these sheep possessed the greatest elasticity without permanent set and the greatest strength in proportion to the character, when they did break the author found the results as follows :—

TABLE OF RELATIVE STRENGTH OF WOOL FIBRE

Southdown	100
Lincoln	68
Leicester	72
Cotswold	64
Australian Merino	85
Shropshire	78
Oxford Down	82
Cheviot	75

Since these experiments were made, a much wider and most complete series of investigations have been made in the United States, showing the relation between strain, stretch, and elasticity of various wool fibres, and on measurements of length, curl, and fineness, extending over hundreds of experiments, and which have been published by the U. S. Department of Agriculture in a report on the Examination of Wools by Professor M'Murtrie, Washington, 1886, which fairly agree with the above figures as will be seen by the following table, taken from p. 384 of this report :—

TABLE OF RELATIVE VALUES FOR ALL ELONGATIONS

Southdown	100·0
Oxford Down	85·0
Merino	80·5
Lincoln	65·0
Cotswold	61·0

Strength of Wool compared with Metals.—The wonderful strength of the wool and other allied fibres almost challenges comparison between them and metallic wires of various kinds of equal cross section, and in the above-named report a series of detailed experiments were made (p. 358), with a view to determine these relations, and they are graphically expressed in a series of curves, and the following is the summary of results:—

1. The curve of the total stretch for wool is of about the same inclination as that for wrought-iron, but it is concave upwards, the iron curve being convex.

2. The tensile strain for wool is about one-half of that required to produce the same per cent of total stretch in a wrought-iron bar of equal cross section.

3. A permanent set commences in wool at about 50 per cent of the amount of strain required to originate a set in a wrought-iron bar, or at about 37 per cent of the ultimate tenacity of wrought-iron of good quality.

4. For steel the corresponding value is 34 per cent.

5. The ultimate average tenacity appears to be nearly double that of average cast-iron of equal cross section, about $\frac{4}{5}$ of good wrought-iron, and a little more than $\frac{1}{3}$ that of good steel.

6. The maximum stretch of wool is greater than either metal, being 1·75 times that of wrought-iron, 12·8 times that of cast-iron, and 4·5 times that of steel.

7. The permanent stretch or set of wool appears to commence only when the total stretch equals nearly 5 per cent of the original length of the fibres, which is at least 10 times greater than the corresponding value for either metal.

8. The curve for wool most nearly approximates to

that for wrought-iron, but is plainly an ogee curve, while those for the metals are merely concave.

9. The average tensile strength of a wool fibre is about 1131·8 lbs. per square inch.

10. Wool has more than twice the strength of the toughest wood, $1\frac{1}{7}$ times that of bone, 4 times that of white pine, 2·7 times that of ivory, 5·6 times that of whalebone, and nearly as much as soft brass wire, phosphor bronze, annealed iron wire, or steel wire rope.

Curl in Wool.—One of the great peculiarities which distinguishes wool from hair consists in the wavy or curly nature of the fibre, and it is difficult to find any explanation of the cause of this peculiarity. It does not occur within the hair follicle, but soon makes itself manifest after the fibre has passed out of the surface of the skin. No mechanical cause for it is apparent, although it seems in some way to be occasioned by the unequal contraction of the cells on the two sides of the fibre, first in one direction and then in another. It is impossible to detect any feature in the arrangement of the constituent cells to account in any way for this peculiarity, and it appears to be, as in the case of the twist in the cotton fibre, inherent in the very nature of the wool.

In a paper which was read in 1867, before the Queckett Microscopical Club, by Mr. N. Burgess, the writer gives the following as the explanation:—"I am of opinion with respect to the growth of wool, that as soon as the point of the fibre has protruded through the skin of the animal, a series of growths takes place, a small part of the epidermis is converted into wool, and then a rest ensues. One side grows faster than another, and hence probably the curly form of the fibre. When another growth takes place another ring is added, the new growth pushing up the

hair from below and so adding to its length. This process is continually repeated, varying as to the length, straightness, and girth of the joints, and possibly with a variation in the thickness of the cylindrical portion of the fibre."[1] I do not, however, think this is the true explanation, as the epidermis is not converted into wool, the fibre being formed within the hair follicle before its protrusion out of the skin, although the unequal contraction of the various constituent parts of the hair, as the cells become more consolidated after leaving the skin, may account for the phenomena. We must remember that the cells which are to constitute the fibre are large and plastic within the lower part of the follicle, and become more consolidated as the fibre is pushed upwards. The cells which constitute the cortical part becoming elongated by the pressure to which they are subjected by the shrinking in of the outer cells. These outer cells shrink till they completely collapse, and thus form the epidermal plates, although they probably retain the laminated structure, and are capable of expanding again when subjected to variations in pressure, moisture, and temperature; and, as they shrink in, their gelatinous nature enables them to adhere together till they form a solid epidermal layer, which tightly binds the constituent cells of the cortical part. Unequal shrinking of this ring would give a tendency to curl. This curl in wool is not so important a feature as the twist in the cotton fibre, because there we have no other means of interlocking action upon which to rely in enabling the fibres to twist into each other, and thus afford the necessary friction to secure strength to resist the pulling out of the fibres when subjected to longitudinal tension; whereas, in the case of wool, we have the scales on the surface which form

[1] *Journ. Queckett Micro. Club*, vol. i. p. 30.

interlocking surfaces quite independent of any twist in the fibres themselves. We may also notice that cultivation increases the curl of the wool fibre in just the same way as the twist in the cultivated cotton fibre, which shows very little of this peculiarity when in the wild state. And both wool and cotton, the one an animal and the other a vegetable product, both tend to revert to the non-twisted or straight condition when their culture and tending is neglected. There is no doubt, however, but that the curl in wool is a most valuable property, and from whatever cause it arises, it seems to increase or diminish just as the finer and more beautiful character of the wool does. The coarser wools exhibit the curl least, and the finest the most.

The following table gives the general relation between the number of curls or waves and the diameter of the fibre :—

Wool.	Curls per Inch.	Diameter of Fibre in Decimals of an Inch.
Australian Merino . . .	24 to 30	0·00064
Southdown	13 to 18	0·00078
,, ...	11 to 16	0·00100
Irish (Roscommon) . .	7 to 11	0·00120
Lincoln	3 to 5	0·00154
Northumberland . . .	2 to 4	0·00172

This relation between the fineness of the fibre and the number of curls has been noticed by all observers, and Bohn (in his *Schafzucht*, vol. i. p. 182) gives the following table, which represents the relation between the curl and diameter of fibre as exhibited in the different grades of wool which are employed as standards of quality. The measurements are translated from the French to the standard of the English inch.

Quality.	Number of Curls per Inch.	Measurement of Diameter of Fibre.	
		In Thousandths of an Inch.	In Fractions of an Inch.
uper Electa Plus plus	32 and above	0·4921 to 0·5905	$\frac{1}{2031}$ to $\frac{1}{1693}$
Super Electa Plus	30 to 32	0·5905 ,, 0·6299	$\frac{1}{1693}$,, $\frac{1}{1587}$
Super Electa	28 ,, 30	0·6496 ,, 0·6988	$\frac{1}{1587}$,, $\frac{1}{1430}$
Prima Electa	26 ,, 28	0·6988 ,, 0·7480	$\frac{1}{1430}$,, $\frac{1}{1336}$
Secunda Electa	24 ,, 26	0·7480 ,, 0·7885	$\frac{1}{1336}$,, $\frac{1}{1267}$
Hohe prima	23 ,, 24	0·7885 ,, 0·8759	$\frac{1}{1267}$,, $\frac{1}{1141}$
Prima	21 ,, 23	0·8759 ,, 0·9448	$\frac{1}{1141}$,, $\frac{1}{1058}$
Geringe prima	20 ,, 21	0·9448 ,, 0·9999	$\frac{1}{1058}$,, $\frac{1}{999}$
Hohe secunda	19 ,, 20	0·9999 ,, 1·4096	$\frac{1}{999}$,, $\frac{1}{952}$
Secunda	17 ,, 19	1·4096 ,, 1·1417	$\frac{1}{952}$,, $\frac{1}{876}$
Geringe secunda	16 ,, 17	1·1417 ,, 1·2499	$\frac{1}{875}$,, $\frac{1}{799}$
Tertia	13 ,, 16	1·2499 ,, 1·4566	$\frac{1}{799}$,, $\frac{1}{686}$
Quarta	0 ,, 13	1·4566 and below	$\frac{1}{686}$ and below

A far more exhaustive series of tests to determine the relationship between the number of curls per inch and the length and diameter of the fibres of a wide range of wools is also given in Professor M'Murtrie's report, but generally they may be said to agree with this table, and although a large number of recapitulations and reductions are made, they only serve to show what a wide range of variations can occur in fibres, both in the same sheep and in the different classes of sheep, dependent upon health, climate conditions, and purity of breed.

Felting of Wool.—Mr. Burgess, in the article quoted above, is of opinion that the sole cause of felting in wool arises from the curved nature of the hair, and has nothing whatever to do with the number of serrations on the surface. He says, "If a fibre be taken from the Merino, and another from the Lincoln sheep, and be laid side by side, the relative proportion of their curves will be as fifteen to one. If a number of these fibres were taken,

each sort separate, it would be seen that the amount of the entanglement between the fibres would be fifteen times greater in the one case than the other. Suppose that instead of their natural form they are laid parallel to each other in a straight line by machinery, each fibre has a natural tendency to regain its original position. Suppose the now parallel fibres are twisted into a yarn, and then woven, and the warp is strained tight in the loom, many of the loose threads having been stuck down in the sizing process, it is evident that in this condition all the fibres are in a state of unnatural tension, until they come out of the loom in the form of cloth. All external tension is now removed in order for the next or felting process; the loose fibres being released, the cloth being saturated with moisture, the whole has to undergo a process of heavy thumping, during which each fibre has a pressure applied first in one place and then in another. I believe that each fibre at every stroke is doing its utmost to regain its curved condition, and as it does so the cloth contracts and becomes thicker. This thickening is in proportion as the fibres of the wool have resumed their curved form from the temporary parallel condition. This, and this alone, is in my opinion, the true cause of the felting process. . . . It is well known to our cloth manufacturers that 'skin' wool, or wool cut after death, felts better than if cut from a living animal. Some may ask how is that to be accounted for? I answer that in death some parts of the animal are distended and others contracted, and this alteration being communicated to the fibrous covering, there would be more room for the contraction of the fibres in the process of manufacture than in those taken off while in the living state. Skin wool is sometimes taken off with lime, or sometimes by causing an incipient state of decomposition,

when the wool separates from the skin, but other causes are at work which are not here discussed."

We think that this view is erroneous, because in that case very curly hair ought to felt quite as well as wool, but it will not, and also because the number of serrations are in some way related to the number of curves, and so the two causes probably go together. The very fact that skin wool felts better than natural wool is an argument in favour of the felting being largely dependent on the nature of the serrations, because when skin wool is examined under the microscope, the action of the lime, or whatever reagent has been used in detaching it from the skin, causes the scales to be less firmly attached to the shaft of the fibre, and the free margins to stand out more prominently, and thus increase the felting property. There are many wools which have a considerable number of serrations but do not felt well; but this arises, not from deficiency in curl, but from the fact that the scales have an attachment to the shaft of the fibre more allied to hair than that of wool, and this applies to the case of the Russian wool, which he mentions as follows: "If imbrications go for anything, Russian Douskoi should eclipse every other in felting, but here again facts are dead against that theory."

We have already noticed that in the case of all wools the direction of the free margins of the scales or lorications on the surface of the fibre is always towards the point of the fibre, or in the direction of the growth, and pointed out that this is very important in the economy of the animal, because it always enables the hairs to slide over each other without felting, which they would certainly do if the free margins of the scales were opposed in direction in contiguous fibres. This freedom from felting when on the body of the animal is further increased by the fact that all fleeces and

the surfaces of the individual hairs are always covered, when in the natural state, by a quantity of unctuous or fatty matter, which is secreted from the skin, and serves as a natural pomatum to lubricate the surface of the fibres, and thus enable them to slide over each other with greater freedom. This secretion, which is called yolk or suint, differs in quantity and quality in different breeds of sheep, and appears to have an important influence on the character of the wool, by promoting its softness and pliability, as well as preserving the surfaces of the wool fibres from injury, and thus enabling them to retain the felting property unimpaired, until required for manufacturing purposes.

Cots.—Under certain conditions the wool does felt on the back of the sheep, and forms what are known as *cots*, which are nothing more than a tangled mass of fibres, but are a source of annoyance to the manufacturer and loss to the farmer, as they deteriorate the value of the wool, and have to be removed in the process of sorting. The cause of this cotting is somewhat obscure, and varies much, both in different sheep and different seasons. I have frequently found that there is an absence of suint amongst the cotty mass as compared with the free fibres, but whether this is a cause or effect I cannot say, since either the tangling may arise from want of lubrication of the fibres, or the thickness of the felt may hinder the free discharge of suint from the skin. This tendency also varies much in individual sheep, and may arise from individual action, such as restlessness or rubbing when lying down, which causes the fibres to be thrown across each other in all directions, and thus they become entangled and matted. Of the chemical nature, and the purpose which this grease or yolk subserves in the nourishment of the wool, we shall have to speak more fully afterwards.

When intended for manufacturing purposes, the wool has to be freed from this yolk so as to prepare the fibres for felting action, and by the processes of preparing the wool the fibres are transposed in position, so as to enable the opposing edges of the scales to come in contact with each other and interlock. This they do with great ease and tenacity, and this increases with the quality of the wool and the fineness and sharpness or pointedness of the scales.

Felted Cloth.—When a piece of felted cloth is examined under the microscope, all the fibres are found to be lying in different directions, and the points of the scales driven into the openings beneath the scales of other fibres, and in many instances the fibres are twisted round each other in such a way as to render the attachments of the scales possible on all sides of the interlocking hairs. When subjected to beating and motion the interlockings are rendered more and more numerous, and the scales driven down into each other with such force that it is quite impossible to tear them asunder without the complete disintegration of the fibres themselves.

A single sight of such a piece of cloth enables us at once to understand the action of many of our machines and processes, such as "milling," where the texture of the cloth is rendered more dense and tenacious. It also enables us to understand why we can make strong threads of woollen and worsted yarn with a far less number of fibres in the cross section than would be required in the case of cotton. There is no doubt also that the felting action is further increased by the curl of the wool, which, when the pressure of weaving or spinning in the direction of the length of the fibre and which had tended to straighten out the fibres is removed, causes them to shrink

up again so as to regain a fuller curve, and thus brings the scales on the surface into closer contact. It is also a noticeable fact that if we wet a lock of wool the curl is considerably increased, but if the lock is subjected to tension while wet, and allowed to dry, the curl is completely removed, because the fibre cells take a permanent set under the strain. The same may be noticed in the human hair, especially when it is long. This arises from the fact that the cells in the anterior of the hair are more or less pervious to water, which, when it enters, swells them out in the direction of the diameter and diminishes the length. Upon this principle the hair hygrometer is constructed. When the air is filled with moisture the hair shortens in length, and when dry expands, and thus moves an indicator over a graduated arc, which roughly corresponds with the degree of moisture in the atmosphere. The cause of the increase in the curl arises from the fact that the cells are not all uniform either in their diameter or symmetrical in their arrangement, and there is, therefore, unequal expansion in various parts of the hair, and on different sides, which tend to distort the shape and twist the hair into curly or waved forms.

Action of Water in Felting.—The action of water, especially hot water, in assisting the felting action is very curious, and is partly probably chemical, especially when acid is added, and there then seems to be no limit to the felting and shrinking action which accompanies it. The constituent cells of the fibre become softened by the action of the water and acid, and seem to be capable of uniting with each other when subjected to rubbing and pressure, until it is difficult, even under the microscope, to detect one fibre from the other,

the whole seeming to form one solid mass, of which the parts unite closer and closer together the further the process is carried. It is not necessary for the fibres to be woven into cloth, or arranged in any regular manner so as to felt; indeed, the reverse is the case, for the less regularity there is in the arrangement of the fibres, the better and more perfect is the felting action. Hence the woollen thread, where the arrangement of the fibres is much more irregular than in the worsted thread, is best adapted for fabrics which are to be shrunk or felted afterwards.

Kemps.—It is quite impossible to pass from the mechanical structure of the wool fibre without noticing some of the variations which the fibre sometimes assumes from the normal type. While there is a general conformity to this type, there is almost a distinct individuality in every separate hair, and all more or less exhibit some peculiarity, which serves to show how little there is in any organic structure which can be looked upon fixed and invariable. This tendency to variation does not astonish us when we remember that, as we have already noticed, such diverse appendages as the nails and hoofs as well as the horns of animals, and the scales of reptiles, or the feathers of birds, are all modifications of the same epidermal layers as the wool and hair. We may therefore look for considerable modifications in the structure of the individual fibres, and we are not disappointed. These variations may occur in all the separate parts of which the wool fibre is composed. Sometimes it occurs in the outer or epithelial layer of the fibre, and we have a great variation in the size and arrangement of the horny plates which cover it, two or three of the plates, or even more, being fixed as it were into one, until we have a considerable length of the fibre

entirely destitute of the imbricated scales, which are such a distinctive feature.

This part of the fibre then appears almost like an ivory ring on the otherwise scaly stem. In many cases this continuity of the outer plates or scales does not appear to be dependent upon the inner structure of the fibre, because that, when examined by transmitted light, remains the same, and the inner cells and even the distinctive medulla are quite visible. These form what are known as "flat kemps," and can be dyed when treated with care, because the central part of the hair is pervious to dye-stuffs.

Sometimes, however, the change is more radical, and the whole substance of the fibre assumes a much more dense appearance, until even the cellular character of the cortical part is entirely obliterated, and the fibre assumes the appearance of an ivory rod, without any internal structure being visible. This peculiarity is much less in the more cultivated than in the wilder and more neglected classes of wool, and is well known under the name of "kemps" or "kempy wool," and is a constant source of annoyance to the spinner and manufacturer, because such fibres not only have no felting or matting power, and thus weaken the tenacity of the yarn, but they always resist the action of the reagents which are used in dyeing, and are apt to remain uncoloured and thus spoil the surface of the fabric. So far as can be judged, they do not seem to differ in chemical composition from the other fibres; but they present such a different mechanical arrangement, and possess no absorbent power, and thus resist the entrance of the dye-stuffs or only receive a topical tincture, which is almost always of a different shade from the other fibres which possess the usual structure and are dyed at the same time.

It is rather singular that these kemps are found in cultivated sheep principally in certain localities of the body, and they are almost always the result of want of trueness in the breed of the sheep. In the finest wools they very frequently occur in the region of the neck, and are almost confined to a ruff round it just where the fibre of the body proper shades into the shorter and coarser hair of the head. They are also frequently found just where the fibre grows shorter on the legs. In the coarser kinds of wool they are found anywhere in the fleece, and are usually of rather larger diameter than the surrounding wool, and shorter in length. These kemps vary in length and coarseness, according to the breed of sheep; as, for example, in the wild Highland sheep they are about two inches long and very thick, while in the cross-bred Australian sheep they are very short. In the finer wools the author has often found them associated together in tufts, as if a small region of the skin was predisposed to their production, and in many cases this only occurs in small portions of the fleece, but in others it is widely distributed. Fig. 49 gives a good representation of these kempy fibres in various degrees. The first two, A and B, are seen by reflected light. A is a fibre where the kempy structure is continuous throughout the entire fibre, which looks like a glass rod, but still has short and faint transverse lines, which indicate the margins of the scales. When the change is a complete one, even the application of caustic alkalis fails to bring out the lamination of the scales with any degree of distinctness, and they seem to be completely attached to the body of the fibre up to the top of the scale. In some cases even the margins of the scales are quite obliterated, and the whole surface of the fibre has a silvery white appearance, not unlike frosted silver. B represents

a fibre where the change is only partial, the top portion of the fibre as well as the bottom portions exhibiting the usual structure of wool, but the intermediate part having the scales closely attached to the surface, and the usual ivory-like appearance within the fibre. Whatever caused this change of character was evidently temporary, and the same follicle produced both wool and kemp. C is a

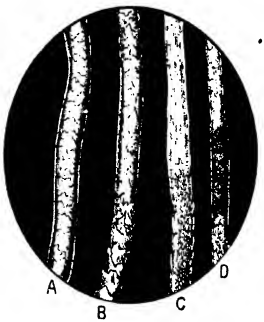


FIG. 19.—Kempy Wool Fibres. × 100 diameters.

A. Kempy fibre, seen by reflected light.
B. Fibre, part wool and part kemp, seen by reflected light.
C. Fibre, part wool and part kemp, seen by transmitted light.
D. Fibre, part wool and part kemp, with kempy part opaque when seen by transmitted light.

kempy fibre seen with transmitted light, where we have the gradual passage of the kemp into wool clearly seen. In this case, with transmitted light, the kempy part retains almost the same transparency as the wool, but exhibits none of the interior arrangement of cells. Fibres which have a tendency to kemp are also frequently distinguished by possessing an unusual distinctness in the medullary cells. Indeed, it frequently happens that the kempy

structure tails off in the same fibre, not, as we should have supposed, so much on the outer surface, but down the interior of the fibre, as though the change commenced in the central cells and was gradually extended to the outer surface as the fibre grew. At the extremity, where the kempy structure first appears, the central cells are often not contiguous, as though the change commenced in a few cells first and then they became more numerous, both in a longitudinal as well as a diametrical direction. These fibres often have a considerable degree of transparency when viewed with transmitted light, and in this respect they vary very much, but they are very seldom as transparent as the adjacent wool fibres. Sometimes they are very opaque, as will be seen in the fibre marked D, where the light seems hardly to penetrate the centre of the fibre although it is refracted at the thinner edges, while the true wool, both above and below, is quite transparent to the same light. In this case the same fibre, when viewed with reflected instead of transmitted light, exhibits no more signs of a dark colour in the kempy than in the unkempy part, showing the want of transparency was not due to colouring matter.

Kempy fibres are not always white and are frequently found in large quantities in coarse coloured foreign wools, especially Russian, and even in the coloured fibres of more cultivated sheep both British and foreign.

CHAPTER X

CHEMICAL COMPOSITION OF WOOL

IMPORTANT as the mechanical structure and arrangement of the parts of the wool fibre are to technologists, they are not more important than the chemical structure and composition, because upon these latter considerations depend the deportment of the fibre in regard to its treatment in many parts of the process of manufacture, and more especially in regard to its relation to the dyeing of the yarn and goods.

Having, therefore, looked at the mechanical structure, we are now in a position to consider what is the typical structure of a wool fibre—

B. In regard to its chemical composition.

We have already seen that cotton and silk are probably definite chemical substances which have a definite and fixed composition, so that we can say that if perfectly pure they would always be composed of the same materials and in the same proportions. This, however, is seldom the case, as they are always more or less associated with other substances, in a state either of weak chemical combination or mechanically entangled.

Thus, cotton, if perfectly pure, would be identical with pure cellulose, which is composed of $C_6H_{10}O_5$; and

silk when degummed would be represented by Fibroin, the formula for which is $C_{15}H_{23}N_5O_6$. It will be seen from this that silk, besides containing an additional element, nitrogen, is far more complicated in its structure than cotton. This remark holds good of all animal fibres as compared with vegetable, and is specially the case in regard to wool, where we have two additional elements introduced beyond those contained in cotton, viz. nitrogen and sulphur.

Protein.—It has already been pointed out that considerable importance must be attached to the source from which fibres are derived, because this determines their relation chemically. All the fibres of vegetable origin are related to each other in having neutral carbo-hydrates as their basis, whether they be cotton, flax, hemp, or any of the bast fibres; while all the fibres which owe their origin to animals, such as hair, wool, or silk, have as their basis a series of substances which are called generally nitrogenous albuminoids, of which albumin, casein, gluten, fibrine, and gelatine may be taken as the leading examples. They are sometimes also called Protein compounds, because Mulder considered that all these bodies contain the same organic group—$C_{18}H_{27}N_4O_6$—to which he gave the name of Protein, combined with different quantities of sulphur and phosphorus. He also thought that the conversion of one of these bodies into the other depends upon the assumption or elimination of small quantities of one or both of these elements. Recent researches, however, have shown that this view is not correct, as few of the albuminoids contain phosphorus as an essential element, and the proportion of sulphur seems to be the same in all. Mulder thought that when treated with caustic alkali the sulphur and phosphorus

could be extracted and the Protein remain, but the sulphur cannot be extracted entirely by the action of alkali, so that the Protein, if it exists at all, cannot be separated. Considering these Proteic compounds under the general term of albuminoids, which are a very numerous group that do not differ much in percentage composition, it may be asserted that they all contain the five elements, Carbon, Hydrogen, Oxygen, Nitrogen, and Phosphorus. It is only in the functional life of a plant that albuminoids can be synthetically produced from inorganic matter, and the animal is absolutely dependent on its vegetable food for the albuminoids necessary for its existence, but it can transform one albuminoid into another or into a substance of the allied Gelatinoid and Keratin groups, and effect their conversion into fats or still simpler oxidation products.

Albuminoids.—All the albuminoids exhibit the same or very nearly the same composition, and within the living animal albumin, casein, and fibrine are constantly being changed from one into the other. When analysed by different chemists, they do not differ from each other more than analyses of the same substance would probably do in different hands, or if derived from a different source. We may look upon their ultimate composition as represented by the following analysis:—

COMPOSITION OF ALBUMINOID

Carbon	53·5	per cent.
Hydrogen	7·1	"
Nitrogen	17·8	"
Oxygen	19·8	"
Sulphur	1·8	"
	100·0	

The three albuminoids mentioned above differ most from each other in the method in which they pass from the liquid to the solid condition. Fibrine separates spontaneously in the solid form from the blood soon after its removal from the living body; while albumin, which is contained in the more liquid portion of the blood, does not become solid without the application of heat; and casein, which is contained in milk, cannot be separated as a solid by heat or spontaneously, but by the addition of an acid. These properties of the albuminoids are important, because, when we come to consider the case of the allied substance, wool, we can readily see how it may be affected by slight changes in the temperature of the water used in washing it, which may alter the molecular condition of its constituent parts, and thus render it more or less fit, as the case may be, for use in manufacturing processes. Albumin commences to coagulate or solidify at 140° F., and is completely solidified at 170° F.

All the albuminoids, as we should expect from their similarity of composition, have many properties in common. They all dissolve in caustic potash or soda, and also in very strong hydrochloric acid. When boiled with caustic alkalies, they yield solutions from which acids precipitate them in a more or less altered state, while sulphuretted hydrogen is given off. The solution in hydrochloric acid has a deep yellow colour, which, however, when brought into contact with oxygen, assumes a fine blue or violet colour. Mercuric nitrate imparts to the solutions of these bodies a very deep red colour, and this reaction serves as a very delicate test for their presence, and enables us to detect the solvent action of various reagents upon them.

All the albuminoids, as they exist in living plants and animals, are in combination with water of colloidation to a greater or less extent, and they can almost all exist in two states, soluble and insoluble in water, but when once dried they are insoluble both in alcohol and ether. When soluble in water the aqueous solutions are coagulated by alcohol and precipitated by salts of copper, lead, and mercury, and also by tannic acid, which has a strong affinity for them, and, indeed, this is the basis of the manufacture of leather.

So far as is known at present, only plants can synthesise an albuminoid from the elementary materials out of which it is composed, and no albuminoid has so far been prepared artificially out of non-albuminoid material. Animals are entirely dependent on plants for the albuminoids upon which their existence depends, but they can and do transform one albuminoid into another or into substances of the allied gelatinoid and keratin groups, and also effect its conversion into fats or simple oxidation products.

All the albuminoids when treated with oxidising agents, such as mixtures of peroxide of manganese, or bichromate of potash and sulphuric acid, yield the same products, viz. acids and aldehydes of the acetic and benzoic series. When subjected to dry distillation they are decomposed and a series of compound ammonias evolved. All the albuminoids possess extremely low diffusive powers, and when examined with polarised light they turn the plane of polarisation to the left hand.

Gelatine is closely allied to the albuminoids, and seems to differ from them, indeed, only in not having any sulphur directly combined with it; and this body enters very largely into the composition of all the animal tissues and cells, since they all yield it when

suitably treated. It swells up in water and dissolves on boiling to a viscid liquid, which becomes a jelly when cold, even if the solution only contains 1 per cent of gelatine. Solutions of gelatine are precipitated by tannic acid, salts of mercury, and alcohol, but not by alum, or by neutral or basic acetate of lead, ferrocyanide of potassium, or dilute mineral acids.

THE COMPOSITION OF GELATINE MAY BE STATED GENERALLY AS

Carbon	50·0	per cent.
Hydrogen	6·6	„
Nitrogen	17·7	„
Oxygen	25·7	„
	100·0	

These figures approximate to a formula $C_{42}H_{66}N_{13}O_{16}$, but its exact molecular constitution has not been determined, because it cannot be converted into vapour and does not form well-defined compounds with other bodies.

In the present state of chemical knowledge we cannot determine what is the real difference between many of these allied bodies, and if we attempt to investigate them by separation and analysis, we probably destroy some of their characteristics as they exist in the organism, and can find no definite clue to the relations which they occupied to each other as integral parts of the membranes and cells.

Horny Tissue.—Although the albuminoids are closely allied to wool and the epidermic structures generally, and probably form the base of them, still they differ in their ultimate composition in a slight degree from these horny tissues, as they are sometimes called. The

epidermis of all animals, and the growths which are connected with it, such as hair, wool, feathers, nails, claws, horns, hoofs, and scales, are almost identical in composition. They usually contain less carbon and more nitrogen and sulphur than the albuminoids, and also probably a larger quantity of water, but whether this water is accidental and dependent upon their mechanical structure, or associated with them in some feeble form of combination as water of hydration, it is at present impossible to say. The general composition of these tissues will be seen from the following analysis of hair, wool, horn, and allied substances, which may be compared with the composition of the albuminoids already given :—

AVERAGE COMPOSITION OF HORNY TISSUE, ACCORDING TO MULDER

Carbon	50·54	per cent.
Hydrogen	6·91	"
Nitrogen	16·83	"
Oxygen	22·07	"
Sulphur	3·65	"
	100·00	

These substances have also been analysed by several other chemists, and although they differ from each other in the exact amounts of the constituents, they are sufficiently near to indicate that these bodies have in all probability a fixed composition so far as the base is concerned, although they may be associated with varying quantities of other matter arising from local and other causes.

Analysis of Wool.—Wool has a very similar composition, as will be seen from two analyses by Scherer and Mulder :—

COMPOSITION OF WOOL

	Scherer.	Mulder.
Carbon	50·65	50·5
Hydrogen	7·03	6·8
Nitrogen	17·71	16·8
Oxygen	20·61	20·5
Sulphur	4·00	5·4
	100·00	100·0

Some years ago the author made a series of analyses to determine, if possible, if there was any difference in the composition of various classes of English wool, and the following were the results :—

COMPOSITION OF WOOL FIBRE

	Lincoln Wool.	Irish Wool.	Northumberland Wool	Southdown Wool.
Carbon	52·0	49·8	50·8	51·3
Hydrogen . . .	6·9	7·2	7·2	6·9
Nitrogen . . .	18·1	19·1	18·5	17·8
Oxygen	20·3	19·9	21·2	20·2
Sulphur . . .	2·5	3·0	2·3	3·8
Loss	0·2	1·0	...	...
	100·0	100·0	100·0	100·0

These analyses were made after purifying the staple, as far as it was possible, by maceration with water, alcohol, and ether, so as to remove all fatty matter, and the fibres were then dried at a steam heat so as to remove all traces of moisture. The loss in the first two analyses probably arose from the endeavour to estimate

the earthy matter always associated with the fibre separately, and which consists of various salts, such as phosphates of lime and magnesia, sulphate and carbonate of lime, and peroxide of iron. In the last two analyses the amount of earthy or mineral ash is estimated along with the carbon. This mineral matter, according to M. Chevreul, amounts in different wools to from 1 to 2 per cent, and some other chemists have placed it higher, but there is reason to doubt whether some of the higher estimates have not arisen from the presence of mechanically attached impurities which the structure of the wool fibre greatly favours.

When dry sheep's wool is treated with hydrochloric acid, containing 0·13 per cent of acid, anhydrous ether, cold water, and alcohol, in succession, and then again exhausted with alcohol and ether, the wool fibre is left free from all soluble constituents, and retains only such impurities as can be removed mechanically. When the wool is thus treated the ether takes up the fat, the water takes up the sweat which is associated with the fibre, and the other liquids take up the yolk or suint, which is a kind of natural soap secreted from the surface of the skin and always found attached to the surface of the wool. In some cases the amount of these foreign substances, after the wool has been thus treated, amounts to from 20 to 50 per cent of the air-dried wool.

Keratin.—From a summary of the analyses of wool which is given in Gmelin's *Handbook of Chemistry*, Dr. E. J. Mills, F.R.S., has arrived at the conclusion that wool is a definite chemical compound, which is known as *Keratin*, and may be represented by the formula $C_{42}H_{157}N_5SO_{15}$, which indicates a very complicated molecule.[1] The great

[1] *Journal Chem. Soc.*, March 1883, p. 142.

complexity of wool will be seen best if we contrast it with cotton and silk, thus—

	Formula.
Cotton	$C_6H_{10}O_5$.
Silk	$C_{24}H_{38}N_8O_8$.
Wool	$C_{42}H_{157}N_5SO_{15}$.

Here, while we have in the cotton molecule only 21 elementary molecules, we have 78 in the silk, and no less than 219 in the wool. In the work on the cotton fibre we endeavoured to realise what might be the possible grouping of the atoms within the molecule, but when we come to such complicated structures as the fibre of wool we cannot possibly attempt to do so, and it will probably be long before the science of chemistry enables us to enter upon this field of investigation. Keratin always contains a larger quantity of sulphur than the albuminoids, and when free from ash, water, and melanin gave on hydrolysis the following monamino-acids[1]:—

Acids.	Keratin from Horsehair.	Keratin from Goose Feathers.
	Per cent.	Per cent.
Glycin	4·7	2·6
Alanin	1·5	1·8
Amino-Valeric Acid	0·9	0·5
Leucine	7·1	8·0
Pyrolidin-2-Carboxylic Acid	3·4	3·5
Aspartic Acid	0·3	1·1
Glutamic Acid	3·7	2·3
Tyrosine	3·2	3·6
Serin	0·6	0·4

Similar bodies are found also in varying proportions in the keratin of the human hair, and considerable quantities of ammonia, which is, moreover, a product of decomposition.

In its chemical relations wool exhibits the characteristics

[1] Abderhalden, *Zeit. Physiol. Chem.* vol. xlvi. p. 31.

both of an acid and a base, and no doubt contains an amido acid in its composition. The ammonia formed by the decomposition is an evidence of an amido group and also the strong affinity for acid dye-stuffs. This acid nature of wool also accounts for the formation of compounds of the fibre with various metallic salts, alkalies, and metallic oxides. With basic and acid coal-tar colours, and with metallic salts, wool yields precipitates of definite compositions, and based upon this Knecht puts forward an hypothesis that lanuginic acid, or rather some insoluble modification of it, forms a constituent of wool to the extent of 30 per cent of its weight, and by this means he explains chemically the reactions which take place during the mordanting and dyeing of the fibre.'[1]

Also for the difference in behaviour in dyeing between wools which have been scoured with alkaline carbonates, or hard water, or treated with metallic salts, and wool which has not been so treated, and therefore its acid properties remain unsaturated. Also it shows why in dyeing certain wools it is necessary to add varying quantities of acid to the dye-bath to obtain the best effects.

Acidity of Wool.—The degree or co-efficient of acidity, which is the figure showing the quantity of an alkali which can be neutralised by a given quantity of wool, has been determined for wool, and some of the albuminoids, and the result is as follows, the figures opposite each giving the milligrams of caustic potash neutralised by one grain of the substance:—

Wool	57·0 grams
Silk	143·0 „
Albumin	20·9 „
Gelatine	28·4 „
Globuline	101·5 „

[1] Thorpe's *Dictionary of Applied Chemistry*, vol. i. p. 703.

Although the amount of acidity in wool may be thus determined, it is not possible to determine the alkalinity in a similar manner, because, although the fibre will absorb alkalies, it does not neutralise them.

Wool treated with dilute solutions of alkali apparently shows no difference from untreated wool in regard to acid and basic dyes, but that it is absorbed and does to a certain extent affect the composition of the wool is shown by an increased attraction for such dyes as Benzo-purpurin and Bordeaux, which will only dye wool in a slightly alkaline bath.

Decomposition of Wool.—How complicated this structure really is, and what a number of different substances may be obtained by its decomposition, will appear from the following results obtained recently by Schützenberger by decomposing purified wool with an aqueous solution of barium hydrate at 170°:—

PRODUCTS OF DECOMPOSITION OF WOOL

Nitrogen (evolved as ammonia)		5·25
Carbonic Acid (separated as $BaCO_3$)		4·27
Oxalic Acid (separated as BaC_2O_4)		5·72
Acetic Acid (by distillation and titration)		3·20
Pyroline and volatile products		1 to 1·50
Elementary composition of fixed residue, containing Leucine ($C_6H_{15}NO_2$), Tyrosine, and other volatile products	C	47·85
	H	7·69
	N	12·63
	O	31·83

When wool is destructively distilled at a high temperature, like most organic bodies it yields a considerable variety of different substances. Williams, by distilling flannel with strong boiling potash ley, obtained a distillate

containing a large quantity of ammonia together with butylamine and amylamine.

Flannel distilled by itself yielded an insufferably stinking oil (probably due to sulphur compounds), accompanied by large quantities of pyrrol, streams of sulphuretted hydrogen gas, and a small quantity of carbonic di-sulphide, with mere traces of oily bases.[1]

It is a question whether we are quite right in supposing that we can exactly represent the structure of the wool fibre chemically by referring that structure only to the organic part of the fibre, and neglecting as a factor either the water of hydration or the mineral constituents. When we have exhaustively analysed the fibre, and broken up the structure into its ultimate atoms, we must remember that in some way or other they were associated with these inorganic factors in the living wool, and that they were associated with it in some such way that we cannot possibly remove them without destroying the structure of the fibre itself.

Moisture in Wool.—With regard to the water of hydration, this is an important matter commercially as well as chemically, because no one can afford to pay for water in place of wool, and it is well known that water is not unfrequently added in order to increase the weight. As the wool is obtained from the farmer it differs very widely in different classes and seasons as might naturally be expected, both in regard to the quantity of moisture and grease associated with the fibre.

The author made a series of experiments with well-washed wool to endeavour to decide how much water was really associated with the fibre as water of hydration,—that is to say, water which really belongs to the fibre in its

[1] *Ann. Chem. Pharm.* vol. cix. p. 127.

natural condition,—moisture which it will take up out of the air when it is left exposed at ordinary temperatures. He found that after drying a number of samples of wool on a Petrie's air-drying machine at about 100° F., and then exposing them to the air in an ordinary warehouse unheated in any way, but with a temperature of about 50° to 60° F., that the following was the result:—

Lincoln hogs	7 per cent gain.
" wethers	9 " "
Leicester hogs	6 " "
" wethers	10 " "
Irish hogs	7 " "
Southdown	9 " "
Skin wool	10 " "

These trials were not made at the same time but extended over several weeks, and as there was no doubt a difference in the quantity of moisture in the atmosphere on the different days, this would influence the quantity of moisture gained by the wool. We may, however, take the average gain, which is 8·28 per cent, as a fair representation.

From these same wools which had gained what they would under the ordinary atmospheric conditions, samples of each were taken and subjected to half an hour's heating in a laboratory oven where the temperature was maintained at the heat of boiling water, which we may take at 212° F. Continued heating, even at this temperature, colours the wool yellow, and, indeed, this change occurs at a considerably lower temperature if continued long. When the various wools were withdrawn and weighed the following was the observed loss:—

Lincoln hogs	13	per cent loss.
„ wethers	13½	„ „
Leicester hogs	14	„ „
„ wethers	13	„ „
Irish hogs	14½	„ „
Southdown	14	„ „
Skin wool	16	„ „

This gives an average loss of about 14 per cent, which appears to indicate a further loss of 5·72 per cent as compared with drying at 100° F.

When this wool was again exposed to the ordinary atmospheric conditions it regained a considerable portion of the loss which had been sustained, but not all. On the average it only regained about 9 to 10 per cent, showing that subjection to a temperature approaching boiling point, even for a comparatively short period of time, destroyed a portion of its hygroscopic qualities, or else drove off more than the water of hydration, and had already commenced to disintegrate certain of the organic compounds which either form part of, or are present within, the fibre cells.

When these experiments were made, little attention had hitherto been given in England to the quantity of water which is necessarily associated with wool, but on the Continent there were official and public testing establishments in many of the large manufacturing centres both in France and Germany, where reports can be obtained in regard to the condition both of wool, tops, and yarn.

Distinction must be drawn between the above figures denoting percentage contents or percentage loss and the following figures showing percentage of regain. The former are based upon 100 of fibre plus moisture, the latter upon the absolutely dry fibre taken as 100.

The various standards of moisture were first authoritatively fixed at the International Congress held in Turin in 1875, and the following are the results:—

Cotton yarn	$8\frac{1}{2}$	per cent	"regain."
Worsted yarn	$18\frac{1}{4}$	,,	,,
Carded woollen yarn	17	,,	,,
Flax and hemp	12	,,	,,
Jute	$13\frac{3}{4}$	,,	,,
Shoddy yarn	13	,,	,,

The regain for silk was fixed by the Lyons Chamber of Commerce in 1840 at 11 per cent, and this received official sanction by the French Government in 1841.

Since then large testing-houses have been established in this country, of which the two best known are those at Bradford, Yorkshire, and at Manchester. Here may be found every appliance necessary to make a complete report on all the properties of raw materials and yarn, and standard tests have been adopted which are now universally accepted in every civilised country.

In these testing-houses the weight taken is usually 2 to 3 lbs., and this is dried in specially constructed ovens, so arranged that the material can be weighed while in the hot atmosphere of the oven, and the drying process noted as it proceeds. The material is placed in a wire basket, suspended in the oven by a wire depending from the beam of a balance standing on the top of the oven, the wire passing through a small hole which does not hinder the movement of the wire. The oven is heated by gas, with a double lining up which the hot air passes, and fitted with a thermometer the reading of which can be taken outside the oven.

The following table shows the standard allowance of

moisture adopted for cotton and other materials at these two testing-houses :—

TABLE OF WATER ALLOWANCE

Material.	Manchester.	Bradford.
	Per cent.	Per cent.
Raw cotton	$8\frac{1}{2}$	$8\frac{1}{2}$
Cotton yarn	$8\frac{1}{2}$	$8\frac{1}{2}$
Worsted yarn	$18\frac{1}{4}$	$18\frac{1}{4}$
Carded woollen yarn	17	17
Tops combed with oil	19	19
Tops combed without oil	$18\frac{1}{4}$	$18\frac{1}{4}$
Noils	14	14
Scoured wools	16	16
Hemp and flax	12	12
Jute	$13\frac{3}{4}$	$13\frac{3}{4}$
Shoddy yarns	13	13
Silk	11	11

It has been found by a number of experiments conducted in these places that if wool is subjected to the highest temperature which it can sustain without scorching that it will regain from 18 to $18\frac{1}{2}$ per cent of moisture, and we may, therefore, regard this as its normal condition under the usual atmospheric conditions.

Of course, this loss in washed wool would probably indicate a considerably larger one on the wool as it comes from the farmer's hands, but there is always difficulty in measuring it because of the large quantity of grease, earthy matter, and other substances which are associated with the wool mechanically.

Mechanical Composition of Wool.—M. Chevreul gives the following as the composition of samples of raw Merino wool, which were analysed by him after drying at a temperature of 212° :—

COMPOSITION OF RAW MERINO WOOL. (CHEVREUL)

Earthy matter deposited by washing the wool in water	26·06 per cent.
Suint, a peculiar saponified grease, soluble in cold water . .	32·74 ,,
Neutral fats	8·57 ,,
Earthy matter obtained after the fatty substances were eliminated	1·40 ,,
Textile fibre	31·23 ,,
	100·00

In this case the water had all previously been eliminated by the drying at 212° F., and yet less than one-third of the total weight remained as pure fibre.

Faist gives the analysis of several wools in a similar manner, but made before the fibre was dried, and he has tabulated them thus:—

ANALYSIS OF RAW WOOL. (FAIST)

	Hohenheim Wool (raw).		Hohenheim (washed and dried).	Hungarian (washed and dried).
Mineral matter . .	6·3	16·8	0·94	1·0
Suint and fatty matter .	41·3	44·7	21·00	27·0
Pure wool	38·0	28·5	72·00	64·8
Moisture	11·4	10·0	6·06	7·2
	100·0	100·0	100·00	100·0

In this analysis, in the case of dried wool, the results agree fairly well with the results of experiments on washed and dried wool, where the drying temperature was 100° F., which gave 8·28 per cent as the loss.

There is always associated with wool a considerable quantity of fatty matter. Part of this fatty matter is only mechanically adhering to the surface of the fibre, and is

the result of a secretion from the skin of the sheep which is known as the yolk, and bears an important part in the growth and preservation of the fibre. The remainder is chemically united with the fibre, or exists as cell-contents in the interior.

With regard to the yolk, Mr. Youatt, in his treatise on sheep, makes the following remarks: "The filament of the wool has scarcely pushed itself through the pore of the skin than it has to penetrate through another and singular substance, which, from its adhesiveness and colour, is called the yolk. It is found in greatest quantity about the breast and shoulders, the very parts that produced the best, and healthiest, and most abundant wool; and in proportion as it extends in any considerable degree to other parts the wool is then improved. It differs in quantity in different breeds. It is very abundant in the Merinos, and is sufficiently plentiful in most of the southern breeds, either to assist in the production of the wool or to defend the sheep from the inclemency of the weather. In the northern districts, where the cold is more intense, and the yolk of the wool is deficient, a substitute for it is sought by smearing the sheep with a mixture of tar and oil or butter." The use of tar, however, greatly detracts from the value of the wool for manufacturing purposes, and is now falling into disuse on this account. This artificial protection to the wool greatly increases the fineness of the staple as well as its strength and lustre. "Where there is a deficiency of yolk, the fibre of the wool is dry and harsh and weak, and the whole fleece becomes thin and hairy; while, where the quantity of yolk is abundant, the wool is soft and oily, and plentiful and strong. Precisely such, in a less degree, is the effect of the salving, in supplying, and increasing, and strengthening the wool."

Suint.—This yolk is termed chemically *suint*, and consists in large part of various soluble salts of potassium which is derived from the soil, and after circulating in the blood is united with various animal acids, and secreted from the skin with the sweat, with which it remains attached to the fibres, or forms a layer near their roots. Formerly this suint was looked upon as a kind of soap, because it was soluble in water, and along with it the wool contained about 8 per cent of fat, but this fat is usually associated with earthy matter, such as lime, and consequently forms a soap which is very insoluble in water. The soluble suint, however, appears to be a definite compound, and is known as sudorate of potassium, arising from the combination of potash with a peculiar animal oil of which very little is known. The recovery of the potash from the washings of sheep or wool has become a large industry in districts where large quantities of sheep or wool are washed. When derived from the wool, the wool is placed in casks, pressed down as much as possible and cold water poured over it. No greasy particles escape with the brown solution, and all the sand and dirt is retained by the wool, which acts as a filter. The solution obtained is boiled down to dryness, and the sudorate of potassium, which has the appearance of baked molasses, is broken into lumps and calcined in retorts. The residue is lixiviated, and the liquors boiled up to 30° or even 50° B. The chloride and sulphate of potassium crystallise out on cooling, while the mother liquid, when boiled down to dryness, yields carbonate of potassium free from soda. The production is generally 140 to 180 lbs. of dry sudorate of potassium, or from 70 to 90 lbs. of pure carbonate, and 5 to 6 lbs. of sulphate and chloride of potassium from every 1000 lbs. of raw wool.

Chemical Composition of Suint.—Buisine found[1] that the substances soluble in water were very numerous, showing the excretion to be an exceedingly complicated body or series of bodies, and containing all the substances or their decomposition products which are usually found in the urine of the herbivorous animals.

They may be classed as fourteen in number

1. Carbonic Acid (CO_2).
2. Ammonium Carbonate ($(NH_4)_2CO_3$).
3. Potassium „ (K_2CO_3).
4. Volatile Fatty Acids, viz. :—
   Acetic Acid ($CH_3{\cdot}COOH{\cdot}$)$C_2H_4O_2$.
   Propionic Acid ($CH_3{\cdot}CH_2{\cdot}COOH$)$C_3H_6O_2$.
   Butyric „ ($CH_3{\cdot}CH_2{\cdot}COOH$)$C_4H_8O_2$.
   Valeric „ ($(CH_3)_2CH{\cdot}CH_2{\cdot}COOH$).
   Capronic „ ($C_7H_{15}{\cdot}CO_2H{\cdot}$).
5. Higher fatty acids which are all present as potassium salts.
   Ænanthic Acid ($C_6H_{13}{\cdot}CO_2H$).
   Caprinic „ ($C_5H_{11}{\cdot}CO_2H$).
   Oleic „ ($C_{17}H_{33}{\cdot}COOH$)$\cdot C_{18}H_{34}O_2$.
   Stearic „ ($C_{17}H_{35}{\cdot}COOH$)$\cdot C_{18}H_{36}O_2$.
   Cerotic „ ($H{\cdot}C_{27}H_{53}O_2$).
6. Fats in a state of emulsion.
7. Phenol ($C_6H_5{\cdot}OH$) as potassium sulphonate.
8. Lactic Acid ($CH{\cdot}_3CH(OH){\cdot}COOH$).
9. Benzoic „ ($C_6H_5{\cdot}COOH$).
10. Oxalic „ ($(CO_2H)_2{\cdot}C_2H_4O_4$).
11. Succinic „ $C_2H_4(CO_2H)_2$.
12. Uric Acid ($C_2(CO)_3NH_4$)$\cdot C_5H_4N_4O_3$.
13. Amido-Acids, viz. :—
    Glycocol,
    Leucine,
    Tyrosine.
14. Colouring matter, same as in urine.

[1] *Comptes Rendus*, No. 103, p. 66, and *Journ. Soc. Chem. Ind.* No. 5, p. 539.

Schützenberger found that when treated with baryta water the products of hydrolysis were analogous to those of the albuminoids which contain imido groups, and these results were confirmed by Proudhomme and Flick, whose researches indicated the presence of imido rather than amido groups, or that the wool molecule in so far as it is stable contains the groups

$$C_2O_2 \left\langle \begin{matrix} N = \\ N = \end{matrix} \right. \text{and the group } CO \left\langle \begin{matrix} N = \\ N - \end{matrix} \right.$$

but does not contain any NH_2 groups. Coloured products would, however, be obtained by the formation of nitrosamines from the NH group, as all secondary amines when treated with nitrous acid are converted into these bodies by the substitution of the monovalent nitroso groups—NO for the atom of hydrogen, which is directly united with the nitrogen.

Although the absorption of nitrous acid by wool and its combination with phenols seems to indicate the presence of amido groups, they are uncertain, as the formation of nitrosamines with the imido groups would also yield coloured bodies with phenols.

Cholesterin.—Suint also contains a substance which appears to have the composition indicated by the formula $C_{26}H_{43}{\cdot}OH$, and which has received the name of *Cholesterin.* It melts at 293° F., and this enables it to be distinguished from *Isocholesterin*, which has the same chemical composition but crystallises in needles which melt at 270° F. It may be obtained by boiling the grease with alcoholic potash, and crystallising the unsaponified residue from alcohol. Cholesterin has a neutral reaction and is without taste or smell, insoluble in water, but soluble in boiling alcohol and in ether, chloroform, acetone, wood spirit, oil of

turpentine, and in neutral fats and fatty acids. It sublimes unchanged at 390° F., but decomposes at a higher temperature. It appears to be an alcohol homologous with cinnamic acid ($C_6M_5 \cdot CH:CH \cdot CO_2H$), and combines with fatty acids forming esters or compound ethers similar to glycerides. When the chloride obtained by the action of phosphorus pentachloride on cholesterin is digested with alcoholic ammonia, a peculiar substance cholesterylamine, having the composition $C_{26}H_{43}NH_2$, is obtained. This substance, as obtained together with cholesterin, by the saponification of wool grease, consists chiefly of an isomeride of cholesterin, which separates from alcohol in white flocks. The portion of wool grease which does not dissolve in alcohol consists of ethers of cholesterin and isocholesterin, while the portion soluble in alcohol contains free cholesterin, and probably also free isocholesterin, together with fatty ethers of both these alcohols.

When wool is thoroughly washed in water so as to remove all the soluble suint, and is then treated with alcohol, the latter solvent extracts a solid and a more liquid fat or oil. The quantity of these two substances amounts to from 16 to 20 per cent of the total weight of the washed and dried wool, and varies with different kinds of wool. When wool is washed in water, dried, and afterwards treated with alkaline liquids, a considerable quantity of these fats are given up, but not in anything like the same quantities as when treated with alcohol. These two fats may be separated from each other by their different degrees of solubility in alcohol, and were examined by Chevreul and named by him respectively, Stearerin (wool-suet), and Elairerin (wool-oil).

Stearerin is a solid fat at ordinary temperatures, but

melts at 140° F. It is quite neutral, and is apparently free from both nitrogen and sulphur. It does not form an emulsion when boiled with water, but by boiling with two parts of hydrate of potash and water an emulsion is formed without the saponification of the fat. It dissolves in 1000 parts alcohol of sp. gr. 0·805 at 60° F.

Elairerin melts at 60° F. and, like stearerin, is neutral and free from nitrogen and sulphur. When boiled with water it forms an emulsion, and is saponified by the addition of hydrate of potash. At the melting point it dissolves in 143 parts alcohol of sp. gr. 0·805. When the two fats are treated together with water and hydrate of potash for 125 hours, in contact with air, no solution is obtained, but the fats appear to be completely altered. On mixing the alkaline liquid with phosphoric acid, and separating the acid solution from the precipitated fat, the latter is found to consist of one or two neutral substances and two fatty acids of different melting points. The alkaline salts of these acids seem to resemble resin soaps. The acid solution yields by distillation a volatile acid which has the odour of valerianic acid, and probably possesses a somewhat similar composition $C_5H_{10}O_2$ ($(CH_3)_2CH{\cdot}CH_2{\cdot}COOH$).

Lanolin is the commercial form of cholesterin, consisting of cholesterol and isocholesterol, isomeric compounds of an alcoholic constitution.

The substance is obtained from wool-oil, which contains about 70 per cent of cholesterin and 30 per cent of various fatty acids. By saponification with soda the wool-oil forms an emulsion with water which is called wool-milk.

When this emulsion is treated in a centrifugal machine the lanolin separates out in an impure state as a cream which can be precipitated by the addition of lime.

The purified product is afterwards kneaded with about 30 per cent of water.

Anhydrous lanolin absorbs about 100 per cent of water, is an antiseptic, and does not become rancid.

On account of these properties it is now very largely used for medical purposes in the preparation of ointments, salves, and plasters, and also in the manufacture of pomades and cosmetics.

It is an excellent remedy for cuts or burns, as being insoluble in water, the wound can be kept cool by using a stream of water as the lanolin will not wash off and bleeding is immediately arrested by it.

It possesses, possibly as a consequence of the water associated with it, a greater penetrating power than any other fat, sinking deep into the layers of the skin, and hence it is used by agriculturists as a salve for the hoofs of horses, and cows, sheep, etc., keeping them soft and elastic, and also as a dressing for leather.

Mineral Matter in Wool.—Along with the other constituents of wool, there is always a considerable variety of mineral matter, and which, although it does not probably amount to more than from 1 to 2 per cent of the whole, is of considerable importance when viewed in relation to the reactions of colouring matter upon the fibre, because the combinations of these mineral constituents, to a certain extent, undoubtedly act the part of feeble mordants with many dye-stuffs. The author made a considerable number of analyses of the ash obtained by the incineration of various kinds of wool, both English and foreign, which were checked by an exhaustive analysis made by Mr. W. H. Wood, F.I.C., F.C.S., which may be taken as a typical example.

ANALYSIS OF ASH OF LINCOLN WOOL

	Whole Ash.	Soluble Ash.	Insoluble Ash.
Potassium oxide K_2O	31·1	42·3	trace
Sodium oxide Na_2O	8·2	17·3	trace
Calcium oxide CaO	16·9	4·5	51·2
Alumina Al_2O_3 / Ferric oxide Fe_2O_3	12·3	3·6	37·7
Silica SiO_2	5·8	4·1	11·1
Sulphur trioxide SO_3	20·5	24·8	trace
Carbon dioxide CO_2	4·2	3·1	...
Phosphorus pentoxide P_2O_5	trace	trace	trace
Chlorine	trace	trace	...
	100·0	100·0	100·0

The wool was scoured with hard white curd soap, and thoroughly washed with pure water and dried before burning. One per cent of ash was obtained by the burning. On treating the ash with water 75 per cent dissolved, leaving 25 per cent insoluble. The quantity of any of the above constituents corresponding to 100 parts of the wool may be obtained by moving the decimal point two places to the left in the figures given under the column "Whole Ash." In some of these analyses the author found a much larger proportion of ash, in one case at least double, or 2 per cent, but as the excess was chiefly alumina, potash, and silica, it seems probable a more perfect washing would have removed much of this excess in the form of sand and clay, which was probably firmly attached beneath overlapping edges of the epidermal scales. In one analysis as much as 2 per cent of the ash was found to consist of magnesium oxide, in which case the sheep may have pastured in a district rich in magnesian limestone.

It is impossible, of course, to conjecture in what exact

forms of combination or relation these various mineral constituents are built up into the organic structure of the fibre, because the whole is broken up by the application of the red heat, but as they form in less or greater degree a necessary concomitant of all wool fibres, they must influence the relation of the fibre in a chemical sense to other substances.

When dealing with the mineral constituents of the cotton fibre, we pointed out how they probably formed one of the chief reasons why any reaction between unmordanted cotton and colouring matter was possible, since the pure fibre itself consists of cellulose, which is a perfectly neutral and impassive body. The presence, however, of such salts as the carbonate, chloride, and sulphate of potassium, as well as the carbonates and phosphates of lime and magnesia, together with alumina and peroxide of iron, rendered reactions possible, as these being in chemical union with the fibre enabled them to play the part of mordants in certain cases, and thus enable the fibre to unite with colouring matter, or have the colouring matter produced within the fibre walls.

The author made a considerable number of experiments with the purest cotton fibre which could be obtained after the removal of the cotton wax, but in all cases, when brought into contact with reagents, it was impossible by any process at command entirely to free the cotton fibre from them, because whenever liquid transfusion took place a portion of the reagents always remained united with the fibre, and from many of the reactions the author formed the opinion that this resulted from some attraction between the mineral constituents rather than the organic parts of the fibre.

In the same way, but to a much less extent than in the

case of cotton, he is of opinion that these mineral constituents do play a part in chemical changes within the wool fibre, quite independent of the great affinity which some of the albuminoids which compose it themselves possess.

Sulphur in Wool.—Even when wool is only heated to a moderate degree, say above 150° F., it gives off an odour of sulphur, and the same is perceptible when wool is boiled in water, which clearly indicates that considerable quantities are held in feeble affinity by the constituents of the fibre. Sheep's wool dried at 100° F. contains about 1·5 to 3·5 per cent of sulphur, of which it gives up none on boiling with distilled water, but spring or river water takes up some of it, because they usually contain small quantities of alkaline salts in solution.

The amount of sulphur existing in wool does not appear to be a constant factor, but varies in different samples from 0·8 to 4 per cent. In this respect wool is similar to other albuminoids where the amount is always variable, and there is great uncertainty as to the manner in which the sulphur is associated in the molecule. There seems to be evidence to indicate that this element exists in wool in two forms, the one an ultimate constituent of the fibre and the other in a much looser form, and this forms the greater portion.

Treatment with concentrated solutions of caustic soda will remove as much as 84·5 per cent of the sulphur, and in the decomposition products of the albuminoids the following sulphur compounds have been isolated, viz. cystin, cystein, throlactic acid, throglycolic acid, ethyl-sulphide, ethyl-mercaptan, sulphuretted hydrogen, and diethyl-thetin.

Until recently the presence of sulphuric or sulphurous acids had not been observed in the decomposition products of any albuminoids, which led to the opinion that the

albumin molecule did not contain sulphur in combination with oxygen; but Rarkow found (*Chem. Zeit.*, 1905, p. 900), that when purified unbleached wool is treated with phosphoric acid considerable quantities of sulphurous acid are evolved.

In wool, however, considerable quantities of sulphur can be removed without any structural alteration being observed and can be readily split off to form metallic sulphides.

This sulphur cannot indeed be entirely removed even by dilute alkaline solutions, such as soda-ley, but requires prolonged boiling with strong alkalies which, however, destroy the texture of the wool. On this point Chevreul remarks that since the wool disengages sulphur and hydrosulphuric acid without losing its characteristic properties, he is of opinion that sulphur, in its elementary condition, enters into the composition of a body distinct from the filamentous material proper. This sulphur is very difficult to remove entirely, and necessitates great care to prevent discoloration from the formation of dark-coloured sulphides when the wool is allowed to come either in contact with metallic surfaces, or with salts of lead, copper, or iron. This can be easily demonstrated by treating wool washed with water with a solution of plumbite of soda, which can be obtained by dissolving oxide of lead in caustic soda, when the wool will become black owing to the formation of sulphide of lead by the reaction of the sulphur in the wool upon the oxide of lead. This is very important when the wool is to be dyed bright colours.

Chevreul, in the treatment of the wool used at the Manufacture de Gobelins, near Paris, removes the sulphur by soaking the fibre for twenty-four hours in milk of lime at the ordinary temperature of the air, and then washing the wool with dilute hydrochloric acid and afterwards with

water. He found that even when this treatment was repeated forty-eight times, for forty-eight hours each time, the sulphur was not entirely removed, although it ceased to give any reaction with the plumbite of soda. He estimated that the remaining sulphur amounted to as much as 0·46 per cent.[1]

We have already seen that wool is almost identical in composition with the other epidermic tissues, such as horns, hair, or feathers, and like these there is often associated with the wool fibre a colouring matter which exists as a cell-content, and is more especially abundant in the nucleated cells which are often present in the central axis of the fibre. Of the character of this colouring matter comparatively little is known, and yet we know that in various kinds of wool, as in hair, we have every shade represented, from a light straw colour up through brown and red to black. Vauquelin found that fair hair contained salts of magnesia in place of oxide of iron and manganese, which exist in dark hair, and in black hair he was able to distinguish as many as nine different substances, including a greenish-black oil. In red hair he found a red oil present in place of the latter. Some physiologists are of opinion that it is not clearly determined how far the colour of the hair is dependent upon chemical composition, or upon the nature and quantity of the fluid which bathes it, or upon the ultimate molecular arrangement of the hair-substance itself.[2]

Colouring Matter.—When colourless hair or feathers are treated with dilute sulphuric acid by boiling they yield a colourless solution, but when they are black or brown they yield a black or brown solution, and leave a black or

[1] *Dyeing and Calico Printing*, W. Crookes, F.R.S., p. 85.
[2] Kingzett, *Animal Chem.* p. 340.

brown amorphous substance which approximates in composition to albumin. This substance appears to have a composition something like the following:—

COMPOSITION OF COLOURING MATTER

Carbon	55·40	per cent.
Hydrogen	4·25	„
Nitrogen	8·50	„
Oxygen	31·85	„
	100·00	

and may be represented by the formula $C_9H_8NO_4$. The substance is probably a derivative of albumin and possesses a composition of much greater complexity than this formula indicates.

Although the colouring matter in wool and hair is not, when removed from the living organism, very fast to light, it withstands the action both of acids and alkalies. It is never evenly distributed through the substance of the fibre in the same way as the colour of dyes which are applied artificially to the fibre. It usually occurs as a nucleus or nuclei in the lanceolated cells of the cortex, or as endochrome in the medullary cells as seen in Fig. 9. The cell-walls are seldom coloured except in cases where the colour is very deep, and specially in black and red. When artificial colour, such as dye, is applied, however, the reverse is the case, as the walls of the cells are more coloured than the nuclei, and in this case, and especially in coloured wools, the medulla becomes less distinct and the layers more uniform in appearance.

CHAPTER XI

ACTION OF REAGENTS UPON WOOL

In considering the reaction of reagents upon wool the first place must be assigned to the caustic alkalies, because of the very important part which they play in the washing of the wool preparatory to the manufacturing process. Like all the horny tissues and animal fibres, strong alkaline solutions easily dissolve wool, giving off ammonia, especially with the aid of heat, and forming a yellow solution which, when treated with acids, gives off hydrogen and forms acetic, butyric, and valerianic acids, also leucine, tyrosine, etc.

Even when the solutions are not strong, all animal fibres suffer partial decomposition by the action of carbonated alkalies, and especially when assisted by an elevated temperature.

In using any alkali or alkaline salts, of any kind, as a cleansing agent, it is, therefore, specially important that the greatest care should be taken in regard to both the strength of the solution and the temperature at which the solution is applied. The latter point, viz. the temperature of the solution, is a most important matter, and is one which must never be overlooked in our washing processes.

Influence of Temperature.—It has been seen that the real base of the wool fibre is a body which very closely resembles, and is allied to, the albuminoids, and all these bodies are subject to very great changes in molecular condition when subjected even to moderate degrees of heat. The wool fibre, probably, in the natural state contains, as the largest element in its composition, a series of several albuminous bodies which form the walls of the constituent cells and the covering membranes of the epidermal scales, and it is difficult to understand how a very slight change in the temperature, even without the presence of any alkali, can be made without affecting these. The author made a series of experiments with a bright-haired wool with a view to determine how far the lustre and strength were affected by the application of different degrees of heat without the presence of any alkali whatever. So far as the brightness of the hair was concerned, it is somewhat difficult to estimate exactly the changes which occur, even over a considerable range of temperature, because, as the results have to be measured by the comparison with small quantities, there is a wide margin for error arising from the difficulty of presenting them under the same illumination, but if the range is a wide one, say 100° F., there is no difficulty in seeing how serious the question of temperature becomes.

Action of Water on Wool.—Wool which looked quite bright when well washed with tepid water was decidedly duller when kept for some time in water at a temperature of 160° F., and the same wool when subjected to boiling water, 212° F., became quite dull and lustreless. When examined under the microscope the cause was quite apparent. The scales of the wool when only treated with tepid water had a smooth horny appearance with an

almost metallic lustre when seen by oblique light. When treated for some time at 160° F. the lustre was decidedly less and the scales had more the appearance of a smooth paper which was unglazed. When treated with boiling water the lustre was still further diminished, and the appearance like that of dull white blotting paper, with a more or less fibrous structure apparent. If the boiling is continued long enough, when the water contains even very small quantities of an alkali, the whole of the surface of the wool, and indeed the substance of the wool itself, is dissolved into a jelly-like mass. We can also easily see how important the question of the quality of the water becomes, because many spring waters contain considerable quantities of alkaline salts which react upon the free sulphur in the wool, and at elevated temperatures these chemical changes tend to set up a partial dissolution of the covering surfaces of the fibres.

When tested for strength, the same fibres which carried on the average 500 grains before boiling, only carried 480 grains afterwards. The matter is still more serious when the liquid used contains caustic alkalies, because these have a direct action on the fibres even in the cold. Alkalinity is, indeed, in most cases unfavourable for the treatment of wool, and although absolutely necessary in some cases, as the dyeing of indigo, which can only be applied in the alkaline state, this should be reduced as far as ever possible so as to prevent injury to the fibre. Extract of indigo may, however, be used in dyeing from an acid solution.

The continued action of boiling water decomposes the wool to a certain extent, as both ammonia and hydrogen sulphide may be detected in the gases which are given off.

When wool is decomposed in this manner the soluble

products show all the characteristic properties of the peptones, and Suida suggests that this action of boiling water upon wool may account for the lack of fastness to rubbing often noticed with basic colours on wool.

When wool is heated to 266° F. under pressure the fibre becomes completely disorganised, and on drying may be rubbed into a fine powder. At higher pressures and temperatures it is entirely dissolved and will set like a jelly.

Dr. Knecht proposed to separate wool from silk in mixed goods by treating the fabric under pressure at 266° F., as the silk is not affected and the wool becomes carbonised and can be removed as a powder when dry. This process has not been commercially used.

Action of Alkalies on Wool.—Although the action of alkalies on wool, even when very dilute, is quite appreciable, when strong it is very marked, as a 5 per cent solution of caustic soda will completely dissolve wool in about five minutes. There seems to be a critical point in strength at which the action becomes much more energetic, as Knecht found that even after boiling the wool with a caustic solution, containing 3 per cent of the weight of the wool, for three hours that the wool was not disintegrated, but with 6 per cent the wool was entirely dissolved. The action of cold solutions of concentrated caustic alkalies is very peculiar, as it was found by Kertesz[1] and by Buntrock[2] that while solutions of caustic soda of a strength below 75° Tw. rapidly destroy wool, yet with stronger solutions of 75° to 100° Tw. the fibre was not only not destroyed but became bleached and white in appearance, with a high lustre and a feel and scroop similar to that of

[1] Kertesz, *Färber. Zeit.* vol. ix. pp. 35-6.
[2] Buntrock, *ibid.* vol. ix. pp. 69-71.

silk. The maximum effect was obtained by using a strength of 80° Tw. and subjecting the wool to this treatment for not more than five minutes and at a temperature of not more than 68° F.[1]

Mercerising of Wool.—This action is very similar to the action of cold solutions of caustic soda upon cotton. As Mercer found that when cotton was treated with caustic soda of a sp. gr. of 1·3 or 1·4 the fibres became stronger and fuller, and unripe fibres became as if fully ripe, and converting thin and coarse cloth into strong and fine cloth with improved power of receiving colour and retaining it more permanently; and the author found in 1883 that if the cotton yarn, and especially Egyptian, was mercerised and washed under tension that a very high lustre almost equal to silk was obtained, a process which is now extensively used. This process is called mercerising, after its discoverer. In the case of wool the action of the alkali is rendered more effective by the addition of glycerol to the solution. This action is accompanied by the absorption of a considerable amount of the sodium hydrate and a rise in the temperature. It is not known, however, at present whether this is a true chemical combination with the wool fibre, but the rise in temperature seems to favour such a combination; and it may also indicate a combination with some of the more feeble constituents of the fibre, such as the sulphur, since after the wool is mercerised only about 15 per cent of the total amount previously contained in the fibre remains.

The improved dyeing qualities are also very marked, as the dyeing solutions are more exhausted and the shades deeper with the same strength of bath.

Quantitative analyses have shown that this increase in

[1] Matthews, *Journ. Soc. Chem. Ind.* vol. xxi. p. 685.

absorption occurs with all classes of dyes, as will be seen by the following table given by Matthews,[1] viz.:—

INCREASE IN ABSORPTION BY MERCERISED WOOL.

Class of Dye-stuff.	Increased Absorption per cent.
Basic Dyes	12·5
Acid	20·0
Substantive	25·0
Mordant	33·3

It will be noticed specially how much is the increased affinity for metallic salts which are usually employed as mordants. In mercerised cotton there is a very marked change in the microscopical appearance of the fibre, but with wool the change is not so marked. The scales on the surface of the fibres appear much more adherent to the cortex, as if fused together, and so present a more continuous reflecting surface, which decreases dispersion of the light and thus increases the lustre, but the diameter of the fibres seems to be unchanged. In the case of cotton the increased strength probably arises from the shrinking up of the fibre, which becomes more robust and increased in section, while in the wool it probably, by the fusion of the surface scales, offers greater resistance to being pulled asunder and also no doubt causes the lanceolated cortical cells to shrink in length and increase slightly in diameter, and thus in sectional area, and render the cortex more dense. So far the mercerisation of wool does not appear to have made the same progress as that of cotton for commercial purposes.

Heat of Combination.—It has been noticed that the

[1] *Textile Fibres*, p. 47, Chapman and Hall, London, 1907.

temperature rises in the mercerising solution during the process, and this is dependent on the nature of the material entering into combination with the wool. Vignon[1] has experimented on the amount of heat liberated or disengaged by treating different acids and alkalies acting upon 100 grams of unbleached wool, with the following results :—

Reagent.	Calories liberated.
Potassium Hydrate (normal)	24·50
Sodium	24·30
Hydrochloric Acid	20·05
Sulphuric	20·90

These figures may be taken to indicate the relative degree of acidity and alkalinity in the wool fibre.

Use of Soap in Washing.—Borax, soaps of good quality and as neutral as possible, carbonate of ammonia and caustic ammonia, and stale urine, which contains carbonate of ammonia, are the substances which act upon the wool fibre the least, and can therefore be best used as detergents; but both soda and potash, especially the latter, can also be used without injury if the quantities and temperature are properly regulated. Stale urine is probably the oldest known detergent for wool, and when mixed with about 5 times its volume of water and used at a medium temperature cleanses fine wool very well. The active ingredient is the ammonium carbonate liberated by the decomposition of the urea.

Disulphide of carbon dissolves the suint and fat of wool very easily and completely without injuring the fibre. The disulphide may then, when removed from the wool,

[1] *Compt. Rend.* No. 17, 1900.

be driven off at a steam heat, leaving the unchanged fats behind as a residue. The only bar to its use is its excessive inflammability and explosive character when the vapour is mixed with air. To avoid this danger Mullins placed the wool in an enclosed centrifugal machine into which the carbon disulphide is admitted, and when the liquid is saturated the machine is set in motion, and the wool finally washed with water, which displaces all the disulphide, and the mixture of disulphide and water is then allowed to stand and settle on a tank, when the disulphide is drawn off from below and redistilled for use again. The wool is then washed in the usual way. Experiments are said to have shown that wool cleansed in this way is stronger, will spin to finer counts, and costs very much less than if washed with soap. Also as the wool is never heated when in contact with the disulphide the colour is not in any way deteriorated.[1] The author found good results by the use of chloroform, which is non-inflammable.

Wool Washing.—Many of the soaps used are strongly alkaline, and literally as well as metaphorically *scour* the wool. If we use a soap for our own skin which contains a large quantity of free alkali, we soon suffer from its effects, and the tender epithelial scales of the wool fibre are quite as delicate as the surface of our own body, and no wonder that they are injured, especially when subjected to an elevated temperature. How few, however, of the manufactured soda soaps approach to a neutral character and do not contain a large amount of free alkali, and the same may be said of the potash soaps, which for the treatment of wool are much better than soda, as is shown by the fact that the natural grease on the skin of the sheep,

[1] *Dyeing of Textile Fabrics*, J. J. Hummel, p. 102, Cassell & Co. London.

which feeds and sustains the wool, is largely composed of this substance. When cheap soaps are used we have all kinds of unknown elements introduced,—resin, silicate of soda, china clay, and other bodies—and large quantities of free alkali to enable them to clear a large quantity of wool from grease, without any thought of the deterioration of the fibre.

To wash wool completely, and in the best manner, it is usual on the Continent, and especially with the fine wools in which the suint forms such a large portion of the weight of the fleece, to put it through three operations, viz.:—

1. Steeping in tepid water.
2. Washing in weak alkaline solutions.
3. Rinsing or rewashing in water.

Steeping.—Many wools as now received in the bale have already been washed or steeped to some extent in water, and in such cases a steeping process is unnecessary, and the remains of the yolk or suint do to a certain extent, when brought in contact with the alkali in the soap, assist in the washing process. If this steeping is omitted, when the wool is shipped with the suint attached, many valuable products are lost which are recovered in France, Belgium, and Germany, where large quantities of carbonate of potash derived from this source are manufactured.

In practice the steeping is conducted in several large iron tanks, which can be heated by steam and so connected that they can be filled and drawn off separately or worked in series. The first one is filled with a charge of wool and water at a temperature of about 112° F., and the wool is allowed to steep for several hours until no further suint can be dissolved. The partly saturated water is then run into the second tank charged with fresh wool, and so circulated from tank to tank until it is fully saturated.

Fresh warm water is continually introduced into the first tank until all the suint is dissolved out of the wool, and the tank is then emptied of the wool, which is ready to go to the washing machine. Usually five or six tanks are employed, and the rotation is such that the raw greasy wool is first washed with the most concentrated solution of liquid, and the partly steeped wool with continually decreasing strength, until it is finally brought into contact with the warm water alone. The saturated solution of suint is then gradually concentrated in a suitable furnace in which the waste heat comes in contact with the weakest solution, and the process continued until it is evaporated to dryness and all the organic matter calcined out of the magma.

The water extract consists of potash salts and various fatty acids, but not any wool grease, which is insoluble in water; and 1000 lbs. of wool yields about 140 to 180 lbs. of dry residue, and when ignited in the furnace yields, after all the organic matter has been removed, 70 to 90 lbs. of potassium carbonate and 5 to 6 lbs. of potassium sulphate and chloride.

Washing is now almost universally conducted in machines of which there are many different makes, such as M'Naught's, Petrie's, and others, and which consist of large iron troughs provided with a series of rakes which are worked mechanically and carry forward the wool from the feeding end by successive stages to the final squeezing rollers. These machines are usually placed in series of about three, placed at different elevations, so that the water which enters the highest trough at the roller end can be successively run into the lower machines, and thus the entering wool is washed with the most concentrated solution of the washing liquor, and the washed wool comes

only in contact with the entering water in the highest trough for the final *Rinsing*, and the whole process is continuous.

Grates are placed in the bottom of the troughs through which dirt and other mechanical impurities fall, and the exhausted and saturated liquor drawn from the first trough is run off into stone cisterns, where it is treated with sulphuric acid and the oil and fatty matter from the suint and soap recovered and sold.

Temperature of Washing.—This is a most important point, as the lustre of wool is so easily destroyed when a high temperature is reached. It is safe to assume that the lower the temperature can be kept consistent with removal of the adherent impurities the better for the wool, and the less the alkalinity the better, and specially with fine wools, as it is most unadvisable to extract any of the oil which is other than mechanically associated with the fibre. For manufacturing purposes after the wool is washed there ought always to remain about 1 per cent of oil, otherwise the fibre loses nature and becomes harsh and dry. The temperature ought not to exceed 130° F. if the best lustre is to be preserved.

Oiling of Wool.—After the wool is washed, in order to enable it to undergo the manufacturing process, unless the French system of dry spinning is adopted, it is usual to sprinkle oil on to the wool, and of oils good olive oil has been found best, and is easily removed by backwashing the sliver or the yarn. This cleansing process, however, necessitates retreatment with alkaline solutions which are not good for the wool, and in recent years, and specially on the Continent, in place of olive oil, neutralised sulphated castor oil, or castor-oil soap solutions, instead of oil, have been used with advantage, because these can be removed

without using any alkali by the simple process of washing in soft tepid water.

In the washing of wool the greatest attention ought also to be paid to the character of the water used, and the softer it is, that is to say the less mineral salts which are contained in the water, the better will it be for the character of the wool and the economy of the operation. As a rule the use of spring waters is risky, because they almost always contain more or less carbonate and sulphate of lime. The latter is the most objectionable, because it is very difficult to remove; whereas the former can be removed, partially at any rate, by prolonged exposure to the air or to a boiling temperature. If, however, the water contains very large quantities of soluble salts, it ought not to be used unless it is previously softened by some process, such as the Hyde-Clarke or other methods. If a hard water is used, the salts immediately decompose the soap, the sulphuric and carbonic acids contained in them uniting with the alkali, while the fats and oils unite with the lime to form an insoluble lime soap, which is deposited on the surface and within the meshes of the fibre, and fixes all the grease and other impurities which the washing was intended to remove. Nor is this all, for the insoluble lime soap which is fixed into the fibre attacks all the dye-stuffs which may be afterwards used in dyeing the yarn and renders it quite impossible to obtain either fast or even colours, while it is almost impossible to remove it by any number of subsequent washings when once deposited on the fibre. In the washing of wool we ought also to remember that the fats associated with the wool are of two kinds; those which are only mechanically adherent, and those which are chemically constituent, and probably form an integral part of the fibre cells. We can remove the

former without any deterioration in the quality of the fibre; but it is very doubtful whether if we trench upon the latter we do not injure both the strength, brilliancy, and elasticity of the fibre.

That these conditions are not attended to by the majority of our manufacturers, and indeed hardly ever receive a thought, is a matter of our common experience.

On the Continent the washing of the wool is usually more attended to, with a view to leaving the constituent fats within the fibre undisturbed, and this enables a softer and more pliable fibre to be obtained, as well as a far better condition of both the surface and interior for the reception of colouring matter.

Strong alkaline solutions above 50° Tw. had been discovered by Mercer not to injure but strengthen the cotton fibre; but if the solution is weak the fibre is tendered, especially if the alkaline solution is at a boiling temperature. Unlike cotton, strong or weak alkaline solutions deteriorate wool, because even when sufficiently weak not to decompose the organic structure of the cells of which the fibre is composed, they act on the fatty contents of these cells, and by the removal render the cell-walls more brittle and less elastic, as well as more unable to withstand flexure, by the removal of that which assisted the sliding of the cellular surfaces over each other. When the author treated a sample of wool with an alkaline solution of caustic soda which contained 5 per cent of soda, he found that the same fibres which on an average carried 500 grains before treatment only carried 440 grains afterwards, which gives a diminution of 12 per cent and shows how serious the deterioration is.

This ought always to be remembered when treating wool for the removal of the grease which is mechanically

associated with it, since, if there is an excess of free alkali, this excess, whenever the adhering grease has been removed, immediately attacks the surface of the wool and, penetrating within the fibre, removes the constituent fats which are a necessary part of the cell-contents, and thus deteriorates its strength and lustre, and no after-process of oiling can so well and intimately reassociate grease with the fibre. Even when it is necessary that the constituent fat should be removed in order to facilitate the action of certain colouring matters upon it, it requires to be done by the use of weak reagents, and the author is of opinion that many of these cleansing processes could be much better performed within vacuous vessels, so as to assist the passage of weak reagents into the interior of the fibres, which usually contain considerable quantities of air, and thus resist the passage of fluids into the interior at the ordinary pressure.

Lanuginic Acid.—Under certain conditions the action of alkalies upon wool fibre produces a characteristic acid known as lanuginic acid. It is soluble in water, sparingly so in alcohol, and insoluble in ether. Aqueous solutions yield highly coloured precipitates with acid and basic dye-stuffs, with tannic acid and potassium bichromate it gives precipitates. At 212° F. it becomes soft and plastic and the coloured lakes produced by it also melt at this temperature. Knecht gives the following analyses—

Carbon	41·61	per cent.
Hydrogen	7·31	,,
Nitrogen	10·26	,,
Sulphur	3·35	,,
Oxygen	31·44	,,
	93·97	

This corresponds to the formula $C_{38} H_{60} N_{10} O_{20}$. This

acid is best produced by treating the wool with alcohol, ether, and boiling acetic acid, which remove all sulphur and impurities. The purified wool is then boiled with concentrated baryta water, the excess of baryta being removed by carbonic acid, the filtrate precipitated by lead nitrate, and the copious precipitate washed and decomposed by hydrogen sulphide. The solution on evaporation leaves lanuginic acid, as a yellow, translucent, and uncrystallisable mass. This acid gives salts with both baryta and lead.

The reaction of alkalies upon wool fibre gives a ready means of distinguishing it when mixed with vegetable fibres, as the wool completely dissolves when boiled for some time in potash or soda-ley of a specific gravity 1·04 to 1·05, while the vegetable fibres remain entirely unattacked. Silk, however, dissolves in this solution the same as the wool.

Carbonising.—The action of acids upon wool is very similar to their action upon all the horny structures, but very different to their action upon cotton. We saw that strong acids and alkalies acted upon cotton in such a manner as to strengthen it, while weak acids, especially with the aid of heat, rapidly destroyed the fibre; but destroyed it in a peculiar way, by a process of disintegration, which, while it permitted the component cells to be separated from each other, really left their mechanical structure unchanged, and that upon this peculiarity one of the most successful methods of separating wool from mixed fabrics is based. The treatment of the wool along with acid for the removal of the burrs or vegetable fibres associated with it, and which are very great sources of annoyance in the process of manufacture, does not injure the structure of the wool fibres, although it entirely destroys the others; and, indeed, some experimenters are of opinion that the action of the

acid rather tends to strengthen the wool than otherwise. Herr Weisner, of Vienna, found that when horsehair and mohair were treated with acid which did not exceed 4 per cent in quantity, or the heat above 150° F., fibres which before treating with the acid broke with a strain of 480 grains, afterwards carried as much as 568 grains. When, however, the strength of the acid solution was raised to above 7 per cent the fibres were weakened. The author made a series of experiments with a view to test these results with the longer English wools, but was not able to detect any strengthening influence, as when treated with acid (sulphuric) up to even 10 per cent the average strength of the fibres remained unchanged; but he found that the temperature was a very important point, as with solutions not exceeding 2½ per cent of acid and a prolonged temperature of under even 150° F. the fibre was weakened.

In the case of wool the action is the reverse of that with cotton, for the action of weak acids upon the wool is very little indeed, while even weak alkalies, with the aid of heat, destroy it more or less, and strong alkalies completely. The action of alkalies upon wool seems indeed to be like the action of acids upon cotton; they destroy the bonds between the individual cells while the cell structure remains unchanged, and hence strong solutions of caustic soda or potash are the best reagents for bringing out the cellular structure of all the epidermal substances. When wool is heated along with strong sulphuric acid, the fibres swell out and partially dissolve, and the solution when diluted with water becomes turbid when neutralised with an alkali or mixed with the ferrocyanide of potassium. When wool is boiled for a length of time with weak sulphuric acid the solution yields tyrosine, leucine, ammonia, and other compounds.

Nitric Acid.—When wool or any of the horny tissues are heated along with nitric acid, the fibre swells up and becomes yellow in colour, and ultimately dissolves in it. When ammonia is added so as to neutralise the acid, the yellow solution acquires a darker colour, and at last becomes an orange tint. Van Laer is of opinion that in the first instance xanthoproteic acid is formed, then saccharic acid, and finally oxalic acid. The fact that nitric acid, even when dilute, colours wool yellow, is taken advantage of in the printing of patterns upon woollen fabrics, especially those which have previously been dyed blue with indigo, because in destroying the indigo the nitric acid gives a deeper yellow stain which is quite permanent. The action of nitric acid upon wool and silk is not thoroughly understood, but many chemists are of opinion that the surface is partially converted into picric acid. Acetic acid produces little action upon wool beyond destroying the lustre of the fibre, but it causes it to swell up, and when aided by heat and long-continued application will disintegrate it.

Hydrochloric Acid.—Strong hydrochloric acid produces along with wool the same blue or violet colour which is characteristic of all the albuminous substances when treated with the same acid, and when the action is intensified by heat the wool gradually dissolves. When the acid is very strong its continued application, even when cold, will dissolve the fibre. Weak acid, however, is not attached firmly to the fibre and can nearly all be removed by the action of hot water. Dry hydrochloric acid gas carbonises the fibre and completely disintegrates it when the action is continued long.

Chlorine Gas.—Closely allied to the action of strong acids upon wool is the effect produced by chlorine gas.

All the horny tissues when subjected to chlorine, in an aqueous solution, appear to undergo no change in external appearance, but they become more harsh to the touch, and dissolve completely in ammonia with the evolution of considerable quantities of nitrogen.

When in a concentrated state, chlorine has such a powerful effect upon all fibrous matters that it completely destroys them; but when used in a diluted form it only acts upon them in such a way as to increase their susceptibility to receive colouring matter. In the case of chlorine acting upon cotton, we saw that its action was in all probability increased by the tendency which the cotton fibres possessed to absorb large quantities of gas within the substance of the fibre, in the same way as spongy platinum or bone charcoal. Wool possesses this property of condensation in a marked degree, as we have no doubt all have had experience in the length of time which woollen clothes will retain the scent of various aromatic substances, such as tobacco smoke. It will even attach itself to the hair of the head and beard, as in the case where a non-smoker has been with others who have been smoking in the same room or railway carriage.

The discovery that chlorine increased the power of wool to absorb colouring matter by printing was discovered by Mercer. This action of chlorine upon wool has been very largely used in the printing of mousseline-de-laine, which is prepared for the process by passing the goods through a dilute solution of bleaching powder (chloride of lime), and then through an acid which liberates the chlorine within the meshes of the goods, and but for this discovery the printing of these goods by machinery would have been impossible.

When exposed to the action of dilute chlorine gas wool absorbs considerable quantities which entirely change its character. Its attraction for colouring matter is considerably increased and it acquires a high lustre and a silk-like feel and scroop, but at the same time it loses all its felting properties and becomes harsh. A recent German patent has been taken out which states that the harshness may be considerably mitigated by working the chlorinated wool in a solution of a salt such as citrate of zinc, acetate of iron, or stannate or aluminate of soda, and then after treating in a bath of very dilute alkali, exposure to the air.

Chlorinated Wool has now an established place as an article used in manufacture, and is employed to produce many novel effects. It may be most usefully prepared in the following manner:—

1. The wool to be treated must be very thoroughly scoured so as to remove all traces of oil or fat, as the least traces of these invariably lead to unevenness in the finishing process, and this cannot be remedied when the yarn has been subjected to the next process.

2. The yarn must be steeped for 20 minutes in a cold bath of hydrochloric acid of a density of 1·5° Tw.

3. The yarn is then immersed and worked for 10 minutes in a solution of bleaching powder of a strength of 3° Tw.

4. When removed from this bath it is again treated for about 20 minutes in a bath of hydrochloric acid of the same strength as in No. 2.

5. The yarn is finished by thoroughly washing in cold water until all traces of acid are removed.

The yarn now possesses a silk-like gloss and will not felt.

As a consequence of this, when chlorinated and unchlorinated wool are woven together in a figured fabric and afterwards fulled in milling-stocks the unchlorinated yarn shrinks and felts while the chlorinated yarn remains unchanged; and thus many novel effects in pattern can be obtained as well as the difference in lustre; and these can be further emphasised by varying the character of the wool, some of which felt better than others. In the same way, since the chlorinated wool has increased affinity for dye-stuffs, many beautiful two-colour and shot effects can be also obtained with the same dye-bath when the piece is dyed. When a slight yellow tinge which is sometimes imparted to the chlorinated wool is objectionable, it is better to use sodium hypochlorite in place of the chloride of lime in the third process of preparation, and sulphuric acid in place of hydrochloric acid in the second and fourth processes.

Many years ago Lightfoot took out a patent for preparing wool and other animal fibres to be dyed aniline black by treating them with chlorine. For this purpose, woollen or mixed goods require stronger chlorining than for ordinary colours, and it is recommended to test the completion of the process by ascertaining that the wool does not destroy the colour of a solution of permanganate of potash.[1]

In consequence of the action of chlorine and hypochlorous acid, which attack wool even at ordinary temperatures and turn it yellow, it is quite impossible to use chlorine for the purpose of bleaching wool; but notwithstanding this it is much easier to bleach than either cotton or linen. It is, however, quite impossible to employ either the same materials or the same elevated

[1] *Dyeing and Calico Printing*, by C. O'Neill, F.C.S., vol. ii. p. 45.

temperature which is used in the two latter cases, and hence, whenever a dead white is not required, the process of bleaching wool is only a prolonged and gentle treatment with soap and alkaline carbonates.

Bleaching Wool.—When, however, a brilliant white is required, such as is rendered necessary when the wool or goods are to be dyed or printed brilliant colours, advantage is taken of the action of sulphurous acid upon the fibre, which removes all colouring matter. This may be effected by hanging the moist yarn or pieces in a close chamber filled with sulphurous acid gas, either produced within the chamber by the burning of sulphur, or admitted from some outside source, or else by passing the goods over a series of rollers working within enclosed chambers filled with the gas. The goods always require washing after sulphuring, because during the process a small quantity of sulphuric acid is formed within the fabric which, if not removed, will ultimately act upon the fibres and thus tender them in course of time. No doubt the same cause which enables wool to concentrate large quantities of chlorine or ammonia within the fibre increases the intensity of the action of the sulphurous acid. Excellent results in the bleaching of wool and cloth may also be obtained by employing a solution of sulphite of soda, acidified with hydrochloric acid as the bleaching liquid, and when the necessary whiteness is obtained, washing well with water to remove any sulphuric acid which may be remaining within the fibre.

Hydrogen Dioxide.—There is another bleaching agent whose action upon wool and hair is very effective, viz. hydrogen peroxide (H_2O_2), and its oxidising properties can be easily restrained so as to prevent any injurious action even upon the most delicate fabrics which could

not be treated by the more drastic action of bleaching powder or sulphurous acid. On this account it is now largely used as a hair-wash or dye, since it changes dark hair into any required shade of yellow or straw colour.

To prepare hydrogen dioxide, powdered barium dioxide (BaO_2) is mixed with water and slowly poured into water in a vessel up which carbonic acid gas is passing, when the following reaction occurs—

$$BaO_2 + H_2O + CO_2 = BaCO_3 + H_2O_2.$$

The barium carbonate is then allowed to settle and the clear solution of H_2O_2 decanted and bottled for use.

Action of Acids on Wool.—The action of all dilute and specially mineral acids, appears to be more specific than in the case of the vegetable fibres and wool treated with sulphuric or hydrochloric acid and subsequently washed, causing it to have an increased attraction for colouring matter.

Sulphuric Acid.—When treated with warm dilute solutions of sulphuric acid, it not only shows an increased affinity for acid colours but less for basic colours. With cold aqueous or alcoholic solutions of sulphuric acid, with subsequent washing, the affinity for acid colours is diminished, from which it is concluded that the acid is fixed in the fibre in a different manner than when treated with hot solutions. Acidified wool shows a great increase in its affinity for Alizarin colours. Other acids have a similar action to sulphuric acid, except that in the case of acetic acid, it must be added directly to the dye-bath in order to hinder the fixation of basic or increase the absorption of acid colours.[1] Strong mineral acids completely destroy wool.

[1] Gelmo and Suida, *Berl. Akad. Wissenschaften*, May 1905.

Nitric Acid acts energetically upon wool, and unless the acid is weak and the temperature low the wool is stained a deep yellow. It was supposed this coloration was the result of the formation of picric acid, but it is more probable that it is caused by the production of xanthroproteic acid similar to that obtained by the reaction of nitric acid upon any proteid, and which turns a bright orange when ammonia is added. Nitric acid is largely used as a stripping agent for shoddy.

Nitrous Acid diazotises wool in a similar manner to an amido compound, and may be developed subsequently in an alkaline solution of a phenol into a variety of shades depending upon the specific reagent which is used; and when dyed in connection with metallic salts as mordants these phenol colours are fast to boiling water, fulling, acids, and light. Tin mordant give orange and yellow shades, iron dark browns and olive browns, aluminium orange and chromium and copper garnet.[1]

The action of nitrous acid renders wool harsh and non-hygroscopic and by its diazotising action increases its attraction for basic dyes and lessens it for acid dyes.

Chromic Acid is absorbed by the fibre and a compound formed with the fibre, and is largely used in the form of bichromates.

Organic Acids, such as oxalic, tartaric, acetic, etc., are all absorbed, except in the case of tannic acid, which is very sparingly absorbed; but if used at the boiling temperature and afterwards treated with tartar emetic, $C_4H_4O_6K(SbO)+\frac{1}{2}H_2O$, its affinity towards basic dyes is greatly increased.

The cotton fibre, from the inert nature of the cellulose of which it is composed, is not favourable to the action

[1] Matthew's *Textile Fibres*, Chapman & Hall, Ltd., London, 1907.

of reagents upon it, and with the exception of certain vegetable substances, such as tannin, it is probable that no real union in a chemical sense takes place when the cotton is immersed in solutions of various salts; and it is not improbable that when any real reaction occurs it may be traced to the presence of certain unchanged cell-contents of a more or less astringent nature, or the presence of some of the mineral constituents of the fibre. With the wool fibre the case is altogether different, and its action upon certain salts is remarkable. M. Chevreul made a number of experiments to determine the action of wool, silk, and cotton upon solutions of salts of various kinds, so as to determine to what extent these salts were decomposed. On this point and the related matter, the author cannot do better than quote the digest of these experiments, which is contained in O'Neill's work on *Dyeing and Calico Printing*. He says:—"The method consisted in taking a saline solution of known strength, immersing the fibres in phials of the solutions for a certain length of time, withdrawing them, and then by analysis determining what change had taken place in the composition of the liquid, both quantitatively and qualitatively. The fibres were then washed with water until the water used ceased to remove or dissolve any of the salt used, and they were analysed to ascertain whether any of the salt or part of the salt remained in a state insoluble in water, and lastly, the washed fibres were dyed in various dye-stuffs and their appearances noted in comparison with the appearance acquired by untreated fibres.

"The solutions experimented upon were those of common salt, bichloride of mercury, sulphuric acid, hydrochloric acid, lime water, baryta water, alum, nitrate of baryta,

nitrate of lead, and yellow prussiate of potash. In nearly every case there was found some disturbance in the composition of the liquid; either the fibre had left the solution stronger or weaker by the withdrawal of water or by the withdrawing of salt. With common salt all the fibres took up more water than the proportion present in the solution, leaving it stronger than before. In bichloride of mercury the reverse was the case with both wool and silk, which took up a considerably greater quantity of the salt than the proportion dissolved and retained it very stubbornly. Cotton did not disturb the proportions of salt and water, but retained some of the mercury after long washings. With lime water and baryta water also more solid was removed than liquid. With alum, cotton absorbed water and rejected the salt, leaving the solution stronger; while wool and silk acted in the contrary manner, absorbing more salt than water, and leaving the solution weaker; but in each case, after washing with water until the reagents showed no sulphates present, the dyeing experiments showed that alum or something else remained which enabled fibres to dye distinctly different colours from untreated fibres."[1] It would be extremely difficult, even if it were desirable, to give a satisfactory condensation of all the experiments, but it is perhaps not even desirable, because the application of the results or their relevance to the phenomena of dyeing is not direct or clear. The salts experimented upon are rather unusual; they are seldom or never used alone in dyeing, and the condition of leaving them in the cold presents very little resemblance to the conditions under which they are applied in practice.

Some years later M. Bolley took up the research upon nearly the same principles and by the same methods as

[1] *Mem. de l'Acad. des Sc.* vol. xxiv. p. 449.

M. Chevreul, but with different salts. He experimented with cotton, silk, and wool upon dilute sulphuric acid, sulphate of indigo, yellow prussiate of potash, cream of tartar, neutral acetate of lead, and alum.

He found that, except in the case of yellow prussiate of potash, where no action was observable, all the other salts were more or less changed in composition, except in one or two cases where the action of cotton was negative or doubtful. In the case of sulphuric acid, some of the acid had been attracted by wool and silk, but none by cotton. Sulphate of indigo gave up indigo and a small quantity of acid; cream of tartar lost acidity, but no potash was absorbed; while upon acetate of lead cotton had no action, but silk and wool took up oxide of lead. Alum gave up a sub-salt, leaving the solution more acid than before. Along with these fibrous matters, Bolley ascertained that charcoal had almost the same action, a fact which confirmed him in his opposition to Chevreul's theory of chemical affinity having anything to do with these partial decompositions of chemical compounds. The French chemists Thénard and Roard, long previous to Chevreul's experiments, stated that when wool was put into contact with a solution of alum it absorbed and, so to speak, fixed a portion of the alum without any decomposition of the salt. This alum cannot be removed by any practicable washing in cold water, but when treated with boiling water it yields it up. It, however, requires twenty successive washings to remove it entirely. When wool is boiled with a solution of alum, a portion of the substance of the wool is dissolved in the alum liquor; but it also appears that undecomposed alum is absorbed by the wool. With acetate of alumina these chemists say that wool absorbs the unchanged salt. If the wool is dried some acetic acid escapes, and if the dried

wool is boiled with water it yields up some acetate of alumina, but the alumina from that portion of the acetate which was decomposed remains firmly attached to the fibre. They also state that wool boiled with cream of tartar takes up tartaric acid, leaving in solution a neutral tartarate of potash. What really takes place when wool is boiled with a mixture of alum and tartar is only a matter of conjecture. It is supposed that there may be existing at the same time in the wool, alum, tartarate of alumina and potash and free tartaric acid.[1]

I give these conclusions, extraordinary as they seem to a modern chemist, because in most of the details these authorities are confirmed by Chevreul and Bolley. There is no ground for rejecting them, but as the experiments were made at a time when methods of chemical analysis were much less accurate than they are now, it will be well to receive them with some reserve. Bolley's statement that alum taken up by wool contains more alumina than common alum seems more credible than that unchanged alum should be assimilated.

M. Paul Havrez, of Verviers, in writing upon the subject of wool mordanted with alum, found that a weak alum liquor acted as if it were alkaline, while a strong alum liquor acted like an acid upon the wool when tested by dyeing. He endeavoured to explain this double and opposite action by supposing the accidental constituents in the wool or the water, such as traces of soda left in the wool after scouring, or lime in water, or ammonia resulting from the fibre itself, were influencing the results. M. Stas, the well-known Belgian chemist, suggested that a simple explanation of the phenomena might be found in the dissociation or separation of the constituents of the alum.

[1] *Dumas sur la Teinture*, Sec. 4326, p. 143.

M. Havrez found that this was the true cause, and proved it by numerous experiments. He found that if the quantity of alum be small compared with the wool, say 1 part to 200, the alum undergoes dissociation, hydrate of alumina being deposited upon the fibre. The colours which such mordanted wool dyes up in various colouring matters are what are called of the alkaline sort, that is, as if dyed in an alkaline liquor. If, on the other hand, the proportion of alum is large when compared to the wool, the colours dye up of an acid character, or as if an acid had been present in the dyeing liquor. If the proportion of acid be small, and free acid added to it, the mordant deposited upon the wool is less in quantity, but still has the basic or alkaline character. The conclusions of a very lengthy memoir may be stated as follows :—

(1) Strong doses of mordants of aluminium, iron, chromium, tin or copper act upon wool by depositing an acid salt.

(2) Weak doses of the same mordants act upon wool by depositing upon it a metallic hydrate of an alkaline or basic character.

(3) The wool is the cause of the dissociation of the alum, and its absorption into the fibre with unequal amounts of acids and base.

(4) Additions of acids or acid salts, as bisulphate, bitartrate, or binoxalate of potash to the alum, are equivalent in the character of the mordanting to the addition of more alum.

(5) An increase in the quantity of the water favours the precipitation of the mordant as hydrated oxide.

(6) In judging of the nature of the mordanting by the colours dyed upon the wool, it must be noted

that the colours taken by pure wool itself disguise the effect of the acid or alkaline hydrate to a certain extent.[1]

More recently a paper has appeared in the *Chemical Journal*, by Dr. Mills, F.R.S., and Jokichi Takamine, of Tokio, Japan, on the absorption of weak reagents by cotton, silk, and wool. The object of these researches was to obtain a quantitative measurement of such absorption, and then to ascertain whether the absorption is amenable to the laws already established in other fields of chemical investigation. The researches were divided into two distinct parts, viz. (1), the rate and amount of absorption of individual reagents, and (2), the ratio of absorption of mixed reagents. The wool employed in the experiments was fine cashmere; the silk, a plain pure silk, free from Prussian blue; and the cotton, a pure calico—all in the piece. They were all washed previous to the experiment with weak sodic hydrate water, very weak hydric chloride, and hydric tartarate. The results show clearly that both wool and silk absorb these reagents, and that the greater part of the effect is completed, at the ordinary temperature, in a week's time. Cotton absorbed much less than either silk or wool of the individual acids, and was not, therefore, treated for the mixtures. The reagents used to determine the second question were three mixtures of hydric sulphate and hydric chloride. The proportion of the hydric sulphate remaining the same, while the hydric chloride was in the proportion of 1, 2, and 4. The ratios of absorption appeared from the experiments in the case of silk to be very similar in all the reagents, and wool and silk tend to resemble each other in the weight they absorb of sodic

[1] *Technologiste*, vol. xxxii. p. 345; *Moniteur Scientifique*, vol. xiv. p. 598; O'Neill, *Dyeing and Calico Printing*, vol. ii. p. 49.

hydrate, but wool takes up much more from acid solutions than is the case with silk. The quantities of hydric chloride and sodic hydrate were used in the proportion which HCl bears to NaHO, and when the wool was treated with weak solutions the absorption was nearly in the ratio of 2HCl to 3NaHO. The corresponding results for silk and cotton are as 3HCl to 10NaHO in both cases. There is, therefore, a very imtimate relation between silk and cotton—a relation which, whatever it may be in part, is shown by these changes to be to a great extent of a strictly chemical nature.[1]

Although wool, cotton, and silk have certain reactions in common with various reagents, they are easily distinguished from each other chemically.

Wool and silk are easily distinguished from cotton or linen by drawing out a thread and setting it on fire. The animal fibres shrivel up and leave a shining, tumefied, difficultly combustible cinder, which leaves a large quantity of ash when completely burnt. The smoke has a smell of burnt horn, and turns turmeric brown. The vegetable fibres leave a cinder having the form of the thread, and only a small quantity of ash, while they burn with a smoke which has an empyreumatic smell and reddens litmus.

Wool and silk are also easily distinguished from cotton and linen by the yellow colour which they assume when treated with nitric or picric acid, as the vegetable fibres are not coloured.

Wool and silk also dissolve by boiling with potash or soda-ley of sp. gr. 1·04 to 1·05, whereas the vegetable fibres remain unchanged. When treated with cuprate of ammonium the reverse is the case, as the cotton, linen, and silk dissolve, while the wool is insoluble.

[1] *Journ. Chem. Soc.*, London, March 1883, p. 14.

Wool and silk can be distinguished from each other by a solution of sodic plumbate, which can be prepared by adding caustic soda to acetate of lead till the resulting precipitate redissolves. When wool or hair are treated with this solution they turn brown, in consequence of the sulphur which they contain forming the dark plumbic sulphuret, while the silk, which is free from sulphur, remains unchanged.

Grothe[1] gives the following as the best methods of distinguishing wool and silk:—

(1) Wool, cautiously heated to 130° C., gives off the odour of carbonic disulphide and ammonia, assumes a golden-yellow colour, and curls up, while silk becomes coloured only at 140° to 145° C., and does not curl up.

(2) When the fibres, moistened with potash ley, are dipped in a solution of cupric sulphate and then exposed to the air, the wool quickly turns brown in consequence of the formation of cupric sulphide, whereas the silk remains unchanged.

(3) On mixing the solution of wool in caustic potash with tartaric acid, and then with cupric sulphate, a large quantity of cupric sulphide is formed, and the liquid when filtered exhibits a dark brown-red colour. Silk, treated in the same way, yields a somewhat viscid solution, having a fine violet colour.

[1] *Zeitschr. Anal. Chem.* vol. iii. p. 153.

CHAPTER XII

QUALITIES AND VARIETIES OF WOOL AND THEIR DISTINCTIONS

THE wool fibre consists mechanically of a bundle of spindle-shaped cells, united together at their surfaces by some animal substance which permits of their free motion over each other when subjected to longitudinal strain, and upon this depends the elasticity of the fibre. This inner or cortical part is held together externally by a sheath of more inspissated and flattened cells, of a horny nature, which constitute on the external part of the fibre a series of imbricated plates, which overlap each other in the direction of the free end of the fibre. These plates, which were originally more rounded and hollow cells, were formed by the flattening of the cells on the external surface as the fibre passed upwards within the generating follicle, and are capable of being acted upon and swelled out by the use of certain reagents. Upon the form and arrangement of these plates, as well as the nature of their surface, depend the suitability of the wool for use in textile manufactures and the degree of lustre which the fibres will exhibit, and upon the structure of the cortical cells and their reaction with various dye-stuffs depend the softness, pliability, and power to retain any colour which may be

imparted to it. Chemically the composition of wool exhibits a strong resemblance to that of hair, hoof, and other horny substances, which are generated in the same manner as an appendage of the epidermal tissues of animals, but differs from them in always having associated with it a considerably larger amount of structural fat, colloidal albuminoids, and water, and therefore forms a compound substance which is peculiarly liable to decomposition and change when acted upon by weak alkalis, and even hot water when above moderate temperatures.

All the epidermal structures are liable to variation and change under varying conditions, and especially those which are occasioned by alterations in food, soil, and climate; but, in addition to this, they are also subject to modification by causes which are at present obscure, and which may be exhibited in animals which are otherwise subject to the same conditions, and even in different parts of the same animal. When looking at the structure of the cotton fibre, it was seen[1] that there were variations in the nature of the fibre, even in cases where the fibres were taken from the same boll, and that these differences seemed to depend upon the position of the fibre in the boll, and the varying amount of nourishment and light which was received.

The same variation occurs in regard to the wool fibre, and the extent of these variations from the typical fibre may be considered as follows:—

II.—*What variations from this type structure are presented to us?*

C. In fibres from the same animal and grown at the same time.

[1] Bowman, *Structure of the Cotton Fibre*, p. 110, Macmillan & Co., Ltd., London, 1908.

D. In fibres from the same animal grown in different years.

E. In fibres from the same animal grown under different climatic and other conditions.

F. In fibres from different breeds of sheep grown in different countries.

C.—In looking at the variation in the nature of the wool fibres when taken from the same animal, we can best consider the question by observing the general variation which occurs in the distribution, strength, and length of different fibres in the same fleece. As in the case of all animals, the length and strength of the hair differs materially in different parts of the fleece, the finest and shortest wool being found as a rule in the region of the shoulders and neck, while the longest and strongest is situated on the hind quarters round the region of the tail. Hence, when the wool is to be used for textile purposes, it is quite necessary that the different parts of the fleece should be separated from each other, in order that the various qualities of hair may be used together, because it is quite essential that in order to have uniformity in the quality of the yarn there must be something like a general uniformity in the raw material, so far as the length and strength of the fibre is concerned.

In the first place it must be remembered that the character of the wool is to some extent changed over the whole surface of the sheep by the process of shearing, because it causes the lamb's-wool to be removed, and hence in the second growth the terminal character of the fibres is changed.

This causes a distinction to be made in the wool of the first and subsequent clips. In the case of lamb's-wool, or the first clipping from a one-year-old sheep, the character

of the staple is more or less pointed, and the same distinction is exhibited in the individual hairs. The hairs themselves are also more or less attached at the bottom end, so as to be less free in drawing out, and this wool is called hog-wool, from the name which is usually given to the one-year-old sheep, a hog or hogget. After the first clip the ends of the wool staples are more or less square, and the individual hairs which compose the lock are the same. This fleece is called a wether fleece, and the sheep after its first shearing is called a wether. The topping of the fibres by the process of shearing causes them to grow stronger and firmer, and hence the character of the wether wool is usually coarser and less pliable than the hog, as well as more wanting in the waved and curly structure which is so valuable a feature in first-class wool. The first clip, therefore, from a sheep is the most valuable in a technical point of view, and can be applied to the production of a higher series of counts and a better quality of yarn than the subsequent clippings. The separation of the various qualities of wool in a fleece is accomplished by the process of "sorting," which consists in tearing off each quality separately with the hand. It is unnecessary to say that long practice is required to enable this to be done with precision and accuracy.

It is well known that the quality of the mutton derived from the carcass of the sheep varies in different parts, and is more delicate and finer in the grain on the fore than the hind part of the animal, and on the shoulders than on the legs. In the same way the character of the flesh seems to be transmitted to the wool which grows upon the different parts of the animal, since we find the finest and best-grown wool covering those parts which are finest and best flavoured when prepared as food. This general indication

points to the fact that in all sheep the finest wool is found on the forepart of the animal, and it grows coarser and generally inferior as we descend downwards towards the under part of the belly and backwards towards the tail and flanks. The habits and requirements of the animal also tend to increase these distinctions, since the under parts and flanks of the sheep are subject to greater attrition and fouling than those higher up and more forward.

Sorting.—We can best understand the different qualities of wool which are to be found in a single fleece if we refer to Fig. 50, which gives us a representation of a fleece of English wool, laid out flat upon the sorting board or ground, so that the various qualities of which it is composed can be clearly seen. The fleece itself roughly represents the general features of the body of the sheep—the ridge or back which follows the course of the spine being in the centre, and dividing the fleece into equal halves from the head to the tail.

The distinction in quality between fibres from one part of the fleece and another is so great that a large number of different "sortings" can be made, and of course the number will depend upon the general character of the fleece and the purposes to which the wool is afterwards to be applied. The range of qualities in any individual fleece varies according to whether the fleece is of a fine or coarse breed of sheep. This variation in the quality of different breeds has been compared to "the keyboard of a piano, where each sheep has its octave of qualities; but the octave of the Merino is very high, while the octave of the Lincoln is very low." In the same way the names which are given to different qualities of wool, even out of the same fleece, are very various in different localities, and even amongst different firms in the same neighbourhood,

where special names are given to different classifications, and it is a pity that some general rule is not adopted so as to avoid confusion. In the finer classes of wool the various qualities are often named after the highest counts into which they will spin, and such division has the merit of having a definite basis for classification.

The diagram, Fig. 50, shows the position of the various qualities of wool on a fleece of Leicester hog; but the same relative positions hold good in all kinds of fleeces. The finest and most even grown wool is always found on the two shoulders about the positions marked AA. In some fleeces this quality extends more into E and BB and F than in others, and the quality of the wool at BB is not very much inferior, although rather stronger and coarser. These two qualities would be called in the woollen trade picklock and prime or choice, while the wool found in the position C is frequently finer in the staple but shorter than AA or BB, and apt to be more defaced by irregular or coloured hairs. When free from these defects it forms a super quality. The qualities D and E shade into those on each side of them, and as they form the apex of the neck and shoulders they are less deep-grown or close in the staple than A or C. The quality F closely resembles BB, into which it shades, and for many purposes, especially for spinning down, A, B, E, and F are frequently used as one quality. In Bradford the wool from the shoulders and neck is usually called "blue" or "fine" matching, according as the quality of the fleece may be. In an ordinary Leicester fleece it would be "blue" matching, and would spin to 40's. If, however, the fleece was of a superior quality, such as a fine Kent selected for quality, it would make "fine" matching, and would spin to 42's or even 44's. If the fleece was a strong Lincoln or Gloucester, it

would probably only be classed as "neat" matching, and would in that case spin no further than 36's. Passing beyond F backwards on to the flanks of the sheep the wool becomes long and coarse, the best being found in the positions marked GG, and this would make what is called "brown" matching or drawing, which would not spin

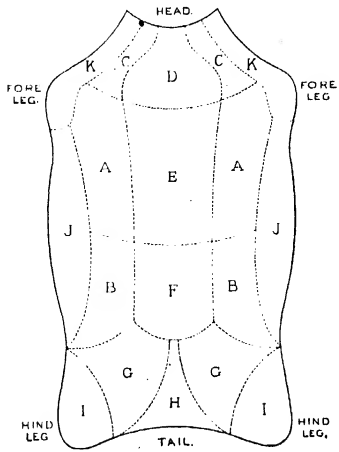


FIG. 50.—Fleece of Leicester Wool. Showing the position of the various qualities of Wool.

higher than 32's, even in fine selected fleeces of English wool, and in many not so high. At H and I I the coarsest part of the fleece is reached, where the wool grows in large locks with long coarse hairs. The latter is called the "breech" or "britch," and can only be used for very coarse yarns and low numbers, not spinning higher than 26's, even when the fleece is comparatively fine in the

other parts. Sometimes it is also called "say cast." From the extremities of I I there is often taken a lower quality still, which is called "tail" or even "cow-tail," from the resemblance which the hair possesses to the strong tuft growing at the end of the cow's tail, and of course this can only be used for the very lowest numbers. There are usually also a quantity of hard lumps, consisting of matted fibre and dirt, which have to be cut off with the shears by the sorter and are called "toppings." These are smaller in proportion as the flock is well tended and the seasons fine. In the ordinary English fleeces all these qualities are long enough to be combed; but just round the edges of the fleece, in the positions marked JJ and KK, and at the furthest ends of D and CC nearest the head, we have a very short-stapled wool, which grows in small tufts or staples called "shorts" or "brokes," and which is used for carding. In quality they correspond to the longer wools with which they are associated in the different positions on the body. They are usually divided into three qualities, which correspond to the blue or fine matching, the neat matching, and the britch. The finest, which are derived from the extremities of D, CC, and the position K, are often called "super" or "downrights." Those which grow on the position JJ, especially the forward part, are called "middle" or "seconds"; and those from the extremities of JJ nearest to I are called "common" or "abb." When the fleece is cross-bred, and even in some cases where it is not, there is always a tendency to the production of "kemps" along the skirt, but specially at the parts marked KK and the extremity nearest the head. Where the kemps occur in the combing wool is most frequently in the region of the tail, in the part marked H.

The difference between the qualities of wool, both in position and quantity, differs very much even in sheep of the same breed and feeding in the same field, as each sheep and fleece has its own "individual" characteristics, with its own special "octave," to refer to the former figure. When the author was engaged in the worsted trade, the fleeces from the same farmer were usually divided into three qualities, "super," "fine," and "common," the names indicating the relative fineness of the average wool which they contained; and only those who have "cased" or classed large quantities of wool know how wide this variation frequently is.

Rankness.—In looking at the differences which exist in the hairs grown on the various parts of the same sheep, we are struck with the fact that the hair follicles, and consequently the hairs, are most numerous on those parts where the wool is the finest in quality, and there is on these parts the largest production of the suint or grease which is exuded from the glands for the nourishment and support of the hair. We saw, when looking at the human hair, that there were about an average of 600 to 700 hairs growing upon every square inch of the head, a quantity which differs considerably in different individuals. On an ordinary English Leicester sheep the numbers are about as follow: 1500 to 1900 on the shoulder, and 800 to 1200 on the flanks, so that they are nearly twice as rank in the one case as the other. In many cases, as in the human subject, there is more than one hair contained within the follicle, and as this varies with different individuals, the numbers of hairs will probably vary even more than these figures express in different sheep. The growth of double hairs also seems to be more numerous in some sheep than others, and also they are more numerous where the fibres

are most rank—that is to say, where the wool is the finest in quality. Although the author has not had the opportunity of observing the rankness of the growth of wool on the finest qualities of sheep, such as the Merino, still, from the seemingly universal rule on the English sheep, no doubt the same proportions also pertain in the relative quantities of wool fibres growing upon the different parts of these fine-woolled sheep.

There are considerable differences in the character of the wool fibres on sheep which are of the same flock, but the differences existing in the structure of the fibres from different parts of the same sheep are frequently greater than those on the corresponding parts of different sheep. As we might naturally expect, where the wool is the best in quality, as on the shoulders of the animal, we find all the best qualities of the wool, such as evenness of length, soundness of fibre, softness, and curl, reach their maximum, and as we depart from this region all these qualities fall off. Wherever the breed of the sheep is true and pure, we find all these characteristics more extensively over the fleece than in those cases where the breed is untrue or mixed; and when we come to look at the microscopical character of the fibres on the different parts of the same sheep, we are struck with the fact that those peculiarities in the structure and arrangement of the scales and the general uniformity of diameter of the fibres, which render the finest qualities and varieties of wool the most valuable, are always found on the fibres grown in those regions of the fleece where the best qualities are found. At first sight it might appear that this is simply the utterance of a truism, much the same as saying that the best wool fibres always grow where the best wool is found; but if we consider the matter, we shall see that this is not the case,

because we know of no necessary connection existing between some of these qualities. Thus, although there always seems to be some relation between the number of epidermal scales per linear inch and the number of waves or curls in the fibre, we do not know of the same universal relation between these characteristics and the uniformity of diameter or the soundness and softness, since we frequently find wool fibres in various classes of sheep which possess numerous scales and curves, and yet are both wanting in uniformity of length and soundness of staple. Notwithstanding this, however, it fortunately happens that whatever care is taken to cultivate the sheep so as to improve its best qualities in one part has apparently a reflex action on the other parts, and affects them beneficially also; and the same care and attention bestowed on any one sheep so as to increase the length of the average staple increases also all the other qualities which are most valuable, and tends to diminish the production of abnormal fibres and increase the microscopic likeness of the fibres to each other. We can, perhaps, best understand this if we examine the fibres taken from two sheep of the same Lincoln breed, and notice the difference between the fibres from the shoulder and britch of each of them.

Fig. 51 gives a fair representation of four fibres, two of them, A and B, taken from the best part of the fleece, and two of them, C and D, from the britch. In the case of this sheep it has evidently been well bred and cultivated, and the fibres, although showing great strength of shaft as compared with fine Southdown or Merino wool, are fairly uniform and equally scaled on the epidermal surface. Although the difference between the two classes of fibre is distinctly marked, yet there is, even in the case of the coarser hairs, C, D, a considerable likeness to the finer

ones, A, B. The greatest difference seems to be that the britch hairs are larger in diameter, and the scales themselves stand out more boldly, but there would be, however, no difficulty in at once identifying the whole of the fibres as of the same class.

When fine Lincoln fibres are magnified to, say, 225 diameters, the large lustrous imbricated scales are very

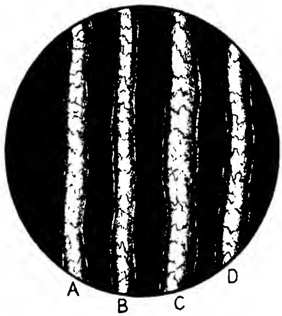


FIG. 51.—Fibres of Fine Lincoln Wool. × 75 diameters.

A and B. Fibres taken from the shoulder. C and D. Fibres taken from the britch.

clearly seen, and the characteristic method of arrangement is shown in Fig. 52.

If, however, we examine Fig. 53, we see a marked difference. These fibres have been taken from corresponding parts of another sheep of the same breed, but in this case the sheep has been poorly bred and only indifferently cared for. Even the fibres A and B, which are taken from the shoulder, are much more irregular in their epidermal scales and in the average diameter, and indeed they almost differ from each other as widely as the fibres from different parts of the

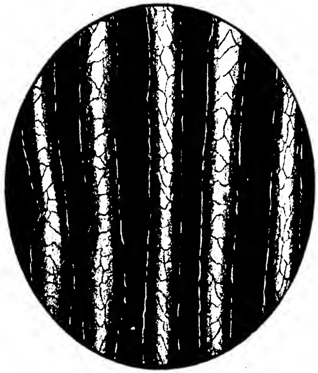


FIG. 52.—Fibres of Fine Lincoln Wool. × 225 diameters.

FIG. 53.—Fibres of Coarse Lincoln Wool. × 75 diameters.

A and B. Fibres taken from the shoulder. C and D. Fibres taken from the britch.

better bred sheep in the last figure. Neither the strength nor general good qualities will be present either. The two fibres C and D, taken from the britch of this sheep, differ very widely even from A and B, much more widely indeed than the fibres taken from the same part of the last sheep do from those taken from its shoulder. It seems as if indeed these coarse fibres had lost many of the character-

FIG. 54.—Fibres of Coarse Lincoln Wool. × 225 diameters.

istics of wool and were reverting to coarse hair, except for the serrated scales, and the difference between the fibres on different parts of this sheep is quite as great and distinct as we shall afterwards find to exist between fibres taken even from different breeds of sheep.

Fig. 54 shows four fibres taken from the britch of a coarse Lincoln sheep, and the arrangement of the scales can be compared with those of the fine fibres shown in Fig. 52, and also with the fibres taken from a coarse Cotswold

sheep shown in Fig. 55, where it will also be noticed that a distinct medulla is visible in many of them.

From this it seems certain that purity of breed and general good management in the cultivation and pasturage as well as the feeding of sheep tends to produce uniformity of characteristics in the fibres of the wool grown on all parts of the body. While, however, the fibres differ in

FIG. 55.—Fibres of Cotswold Wool. × 225 diameters. Showing medulla with endochrome.

length and diameter and the number of serrations or epidermal scales per linear inch, on different parts of the body of the same sheep, it is also wonderful what a variation there is even in contiguous fibres, especially in regard to the diameter.

Diameter of Fibres.—Remarking on this point, Mr. N. Burgess[1] says:—"The size of the fibre is very

[1] *Journal Quekett Microscop. Club*, vol. i. p. 30.

irregular, scarcely any two from the same staple being found alike, and each varying in its own length. In a fibre of Southdown wool, a comparatively uniform species, I have found the size to vary, in $\frac{1}{312}$ of an inch, as much as one-fifth of the whole diameter. The finest Saxon wool I have ever seen gave a remarkable result on being measured. Five hairs in one staple were selected. The finest gave the extremely small diameter of $\frac{1}{3489}$ of an inch, while another fibre lying by its side measured $\frac{1}{1749}$ of an inch. The mean of the fine fibre gave $\frac{1}{2134}$ of an inch. Another sample of Saxony wool gave $\frac{1}{2075}$ of an inch.

"Amongst Saxon wools shown in the grease two of the fibres were measured, and one gave $\frac{1}{1562}$ of an inch, while the other was $\frac{1}{1250}$ of an inch. Probably this sample could not be exceeded for beauty or symmetry. It was taken from one of Steizer's celebrated ewes.

"The Southdown sample shown gives for one fibre $\frac{1}{890}$ of an inch, and another $\frac{1}{520}$ of an inch. The Lincoln wool gives for one part of the fibre $\frac{1}{625}$ of an inch, and another $\frac{1}{520}$ of an inch. The coarsest fibre gives $\frac{1}{466}$ of an inch. The fibre of the Northumberland wool measured in its thinnest part gave $\frac{1}{666}$ of an inch, and in its thickest part $\frac{1}{400}$ of an inch. These examples will suffice for showing the relative degrees of size and the variations which occur in the same fibre."

The author found even greater variations than these, although he also noticed that this tendency to variation in the diameter of individual fibres, as well as parts of the same fibre, differs in different sheep. This may be shown by a number of examples which he measured and tabulated below, and which represent the variation in diameter in different parts of the same fibre:—

VARIATION IN DIFFERENT FIBRES FROM THE SAME PART OF THE SAME SHEEP

Kind of Wool.	Greatest Diameter in Decimals of an Inch.	Least Diameter in Decimals of an Inch.	Difference.
Lincoln Hogs, No. 1 .	·00210	·00192	·00018
,, ,, 2 .	·00180	·00135	·00045
,, ,, 3 .	·00166	·00143	·00023
Average . .	·00185	·00157	·00028
Irish Hogs, No. 1 . .	·00125	·00100	·00025
,, ,, 2 . .	·00183	·00130	·00053
,, ,, 3 . .	·00174	·00124	·00050
Average . .	·00161	·00118	·00043
Southdown, No. 1 .	·00111	·00073	·00038
,, 2 .	·00125	·00092	·00033
,, ,, 3 .	·00100	·00041	·00059
Average . .	·00112	·00068	·00044
Australian Merino, No. 1	·00053	·00014	·00039
,, ,, ,, 2	·00047	·00011	·00036
,, ,, ,, 3	·00041	·00011	·00030
Average . .	·00047	·00012	·00035

In each of these cases the whole of the samples seemed to be fair examples of the different kinds of wool, and they were not deformed by defects which could be traced to bad breeding. They must not, however, be taken as representing the average differences existing in the same locks of their respective wools, but only as instances to show something like the variations occurring, because the author found many specimens which differ much more than these do, although taken at random from locks which happened

to be in his possession at the time when measuring. If we come to coarse and bad-bred wool, such as some of the Russian or Central Asian wool, or even some of our own mountain sheep, we find a range of variation which is almost incredible. In Professor M'Murtrie's report in 1886 to the United States Government Department of Agriculture, a very large series of experiments in reference to this peculiarity are given, and these must have been the result of enormous labour. They are of little practical importance, however, except in regard to the general results which indicate that, by attention to breed and careful cultivation, the maximum of evenness is always attained and so the suitability of the wool for spinning purposes increased. Of course it is not possible on a large scale, in the ordinary processes of manufacture, to take into account the variations in every hair and fibre of the fleece; but the prevalence or otherwise of considerable variations must always be considered, and as there is a great difference in this respect in different classes of wool, it may not be uninteresting to give a series of experiments which the author made at the time when he was practically engaged at the "sorting board," and which were undertaken with the view of determining the relative quantities of the various classes of wool which were to be obtained out of different kinds of fleeces.

Analyses of Fleeces.—These analyses were made not with single fleeces, but with a considerable number, since 240 lbs., or one pack of wool, was taken for each experimental sorting, and these tables are the average of a number of such trials of each kind of wool:—

ANALYSIS OF LINCOLN HOGS

Qualities.		1st Experiment. Weight in lbs.	2nd Experiment. Weight in lbs.	3rd Experiment. Weight in lbs.
Combing	Fine Matching	15·85	17·01	13·21
	Blue ,,	160·00	140·00	154·14
	Neat ,,	40·00	52·00	38·21
Carding	1st Brokes	3·21	4·22	8·65
	2nd ,,	5·58	9·04	7·42
	3rd ,,	1·06	2·75	3·00
Britch or Say Cast		9·68	11·64	8·75
Cow-tail		1·70	1·00	2·31
Cots		·50	·08	1·00
Grey		·01	·12	...
Toppings		1·33	2·14	1·24
Dead Waste		1·05	...	2·07
		240·00	240·00	240·00

Qualities.		4th Experiment. Weight in lbs.	5th Experiment. Weight in lbs.	Average Weight in lbs.
Combing	Fine Matching	22·36	19·41	17·57
	Blue ,,	144·03	150·00	149·03
	Neat ,,	50·11	46·53	45·37
Carding	1st Brokes	5·60	7·31	5·80
	2nd ,,	6·36	8·14	7·31
	3rd ,,	4·21	2·34	2·67
Britch or Say Cast		5·55	4·36	7·99
Cow-tail		·03	1·50	1·31
Cots		...	...	·31
Grey		...	...	·03
Toppings		2·01	·55	1·45
Dead Waste		...	...	1·16
		240·26	240·14	240·00

This table of the sorting of five packs of Lincoln hogs will serve to show the nature of the variation in the different qualities out of five different parcels of this wool, and the average at the end of the table shows something

like what we may expect to obtain as an average out of any lot of the same class of wool. The loss which is called dead waste consisted of small sweepings and dust which it was impossible to gather up, and, as will be seen, in some cases there was a gain instead of loss, probably arising from a slight over-weighing in all the various qualities, or some one of them, as the wool was weighed on ordinary warehouse beam scales.

No endeavour was made in any of these lots of wool to allow for the moisture which might be present over a normal quantity. The wool was undried and exactly in the condition in which it was taken out of the sheets as received from the wool-stapler. The experiments may, therefore, be taken to represent the various quantities of the different qualities, under the ordinary conditions which exist in the wool warehouse. It is quite possible that a part of the dead waste registered in some of the experiments may have resulted from the drying in of the wool consequent on the opening and sorting of the fleece.

The following analysis of Leicester hogs may be compared with the Lincoln hogs just given, and we shall then see the difference in somewhat similar classes of wool:—

ANALYSIS OF LEICESTER HOGS

Qualities.		1st Experiment.	2nd Experiment.	3rd Experiment.
Combing	Fine Matching	24·13	20·40	46·85
	Blue ,,	155·36	140·65	125·21
	Neat ,,	38·51	58·41	45·00
Carding	1st Brokes	6·41	5·58	4·31
	2nd ,,	7·71	6·83	4·14
	3rd ,,	1·31	2·30	3·00
Britch or Say Cast		5·27	4·21	7·11
Cow-tail		...	1·00	...
Cots		...	...	3·14
Grey		...	...	...
Toppings		1·00	·50	1·00
Waste		·27	·12	·24
		240·00	240·00	240·00

Qualities.		4th Experiment.	5th Experiment.	Average.
Combing	Fine Matching	38·74	39·40	33·90
	Blue ,,	138·21	140·21	139·93
	Neat ,,	40·44	38·61	44·18
Carding	1st Brokes	5·25	4·40	5·19
	2nd ,,	3·64	2·83	5·03
	3rd ,,	3·21	3·40	2·68
Britch or Say Cast		6·11	7·30	6·00
Cow-tail		...	·80	·36
Cots		3·21	2·44	1·76
Grey		...	·11	·02
Toppings		·64	·14	·65
Waste		·55	·33	·30
		240·00	240·00	240·00

It will be noticed that in the Leicester hogs the proportion of fine matching is larger than in the Lincoln hogs, but that the blue matching is proportionately less, and there is an entire absence of grey wool.

ANALYSIS OF NORTHUMBERLAND HOGS

Qualities.		1st Experiment.	2nd Experiment.	Average.
Combing	Fine Matching	38·5	36·7	37·6
	Blue ,,	135·3	140·4	137·8
	Neat ,,	42·9	43·8	43·4
Carding	1st Brokes	5·5	4·3	4·9
	2nd ,,	4·1	3·8	3·9
	3rd ,,	3·2	5·7	4·5
Britch or Say Cast		5·4	4·2	4·8
Cow-tail		3·1	1·0	2·1
Cots		...	...	...
Grey		...	...	...
Toppings		1·1	...	·5
Waste		·9	·1	·5
		240·0	240·0	240·0

The experiments with the Northumberland hogs were only made out of two parcels of this wool, and the average is not therefore so reliable as where five experiments were made, but they will serve to show the general character of the wool. In these two instances the wool was rather coarser than usual at the britch, and hence the large proportion of cow-tail.

ANALYSIS OF IRISH HOGS

Qualities.		1st Experiment.	2nd Experiment.	3rd Experiment.
Combing	Fine Matching	32·41	40·30	26·75
	Blue ,,	142·31	150·50	149·10
	Neat ,,	42·50	30·10	46·00
Carding	1st Brokes .	4·28	5·31	6·25
	2nd ,, .	6·50	5·11	5·40
	3rd ,, .	3·90	4·28	2·31
Britch or Say Cast .		5·70	4·40	3·11
Cow-tail . . .		...	...	1·60
Cots		·50	...	...
Grey		...	...	...
Toppings . . .		1·30	...	...
Waste		·60	...	...
		240·00	240·00	240·55
Qualities.		**4th Experiment.**	**5th Experiment.**	**Average.**
Combing	Fine Matching	40·40	30·90	31·15
	Blue ,,	110·10	110·65	114·53
	Neat ,,	38·10	45·31	40·46
Carding	1st Brokes .	4·90	3·61	4·87
	2nd ,, .	6·30	5·40	5·76
	3rd ,, .	3·21	4·00	3·54
Britch or Say Cast .		5·10	4·15	4·49
Cow-tail . . .		1·00	·50	·60
Cots		1·30	4·40	1·24
Grey		...	...	...
Toppings . . .		...	1·20	·50
Waste		...	...	·12
		240·71	240·12	240·26

All these Irish hogs were of a very good quality, and were free, clean wool; the only exception was in the fifth lot, when there were two fleeces which contained a much larger proportion of cots than was found in the other lots, and which brought up the average considerably.

ANALYSIS OF IRISH WETHERS

Qualities.		1st Experiment.	2nd Experiment.	Average.
Combing	Fine Matching	34·51	30·13	32·32
	Blue ..	120·40	125·41	122·91
	Neat ,,	66·31	67·50	66·90
Carding	1st Brokes .	6·40	5·32	5·86
	2nd .. .	4·30	5·15	4·72
	3rd ,, .	5·15	3·80	4·47
Britch or Say Cast .		2·10	2·69	2·40
Cow-tail . . .		...	...	...
Cots		...	...	..
Grey		...	...	...
Toppings . . .		...	.	. .
Waste		·83	...	·42
		240·00	240·00	240·00

When compared with the Irish hogs it will be noticed that these wethers, which were from the same parcel, yield very similar results in the fine matching, but they have a larger proportion of neat and less blue matching. Like the hogs, they were of good quality, and free, clean wool. They were classed by the author as Irish Leicesters, run in Roscommon, and may be compared with the next analysis of Leicester hogs.

ANALYSIS OF HALF-BRED LEICESTER HOGS

Qualities.		1st Experiment.	2nd Experiment.	3rd Experiment.
Combing	Fine Matching	17·01	20·40	16·71
	Blue ,,	100·00	120·00	105·32
	Neat ,,	91·10	68·10	87·14
Carding	1st Brokes .	1·22	5·20	1·32
	2nd ,, .	9·04	7·11	8·21
	3rd ,, .	2·75	3·65	8·03
Britch or Say Cast .		9·75	8·30	7·56
Cow-tail . . .		2·00	3·11	1·20
Cots		·08	1·00	...
Grey		1·12	1·31	...
Toppings . . .		2·11	1·40	1·00
Waste		·79	·13	·51
		240·00	240·00	240·00

Qualities.		4th Experiment.	5th Experiment.	Average.
Combing	Fine Matching	24·50	19·35	19·59
	Blue ,,	114·12	113·91	110·90
	Neat ,,	71·71	80·40	79·75
Carding	1st Brokes .	5·26	6·10	5·02
	2nd ,, .	8·31	7·31	7·99
	3rd ,, .	4·00	2·80	4·25
Britch or Say Cast .		6·50	5·30	7·50
Cow-tail . . .		2·00	1·90	2·04
Cots		·50	...	·31
Grey		·80	...	·64
Toppings . . .		2·00	2·30	1·77
Waste		·30	·60	·24
		240·00	240·00	240·00

In these half-bred hogs it will be noticed that the average of the fine matching is less than any of the other full-bred wools except the Lincoln, while the blue matching is less than in any of the other examples. All these wools were specially sorted for the manufacture of 30's super, for

export. Out of the fine matching in the hogs 40's super were spun. The author never had the opportunity of sorting many of the fine English or foreign wools, and therefore cannot give any analyses of these; but from an examination of such wools at the Indian and Colonial Exhibition and other places on a large scale, he is of opinion that they will run somewhat similar in quantities of the various kinds, bearing in mind always that the classification will be much finer all through, and in all probability the very coarsest classes and the grey, cots, and toppings omitted almost entirely.

The classification of the sorting will vary with each individual firm, and it would be difficult to find even two sorters who could agree as to the exact line at which the division of the fleece should take place. As a check against the author's analyses he gives below a table taken from the Supplement to *Ure's Dictionary*, p. 983, in which a series of sortings are given from various classes of English wool, and these are given in percentages, or lbs. per 100 lbs. of each sort. As they include some of the finer varieties, such as Kent and Norfolk wools, and wethers as well as hogs, they are additionally valuable :—

ANALYSIS OF ENGLISH WOOLS

Name.	Fine Drawing.	Blue Drawing.	Neat Drawing.	Brown Drawing.	Britch or Say Cast.	First Brokes.	Second Brokes.	Third Brokes.	Toppings or Shirlings.
Lincoln Hogs .	0	24	50	15	7	1	1	1	1
Yorkshire ,, .	5	30	38	15	7	2	1	1	1
Leicester ,, .	8	24	30	15	5	2	3	2	1
Northumberland Hogs	9	25	36	15	7	3	3	1	1
Nottingham ,,	7	24	35	20	7	2	3	1	1
Norfolk ,,	30	25	10	10	7	3	2½	1	1½
Lincoln Wethers .	0	12	50	25	7	2	2	1	1
Yorkshire ,, .	0	36	40	12	6	2	2	1	1
Warwick ,, .	4	31	40	12	5	3	2	2	1
Somerset ,, .	4	35	29	18	6	2	3	2	1
Kent ,, .	56	20	10	7	4	½	½	½	½

These examples, however, will serve to show something like the proportionate weight of the range of qualities which are to be found in the deep-grown wools. The various experiments in each table show the variation in different lots of wool taken out of different parcels in the same year.

Diseased Wool.—It is impossible to pass from the consideration of the character of the fibres on the same sheep in the same year, without pointing out how very greatly this character is influenced by the health of the sheep. In sorting any parcel of wool the sorter often comes across some special fleece, the very handle of which is different from the others—the fibre seems leaner and softer, and often seems to have lost both its elasticity and tenacity. When the strength of the staple is tried the locks are readily broken, as if the staple was rotten. When examined under the microscope, the fibres are seen to be generally finer or smaller in diameter than the usual

run of the fibres in the same lot of wool, and often this fineness only extends to a part of the fibre, as if the sheep had been temporarily indisposed, and during that time the vitality of the animal was so much lowered that the usual growth of the wool fibres could not be maintained—the wool sharing in the weakness of the animal. Fig. 56 is an illustration of a number of such fibres, and here we see the

FIG. 56. Fibres of Diseased Wool. × 80 diameters.

A. Attenuated fibre.
B. Fibre with diminished number of epidermal scales.
C and D. Fibres with alternate attenuation and diminished epidermal scales.

nature of the variations. Sometimes the whole texture of the fibre becomes finer, and, while the same proportion of lorications is maintained, the diameter of the fibre is much diminished, as in fibre A; while in other cases the number of scales in the same length seems to be diminished also, and the scales are less prominent and finer in texture, although fewer epidermal cells were grown in the same time, as seen in fibre B. Sometimes these variations occur at frequent intervals, as though the animal experienced

alternate periods of health and sickness, as in fibres C and D. It will also be noticed that in many cases the scales are imperfectly formed, and many perforated so as to show the darker cortical layer beneath. But in all these cases a permanent weakness is introduced into the structure of the fibre which is very deleterious to its use in yarn, as being entirely wanting in evenness of strength and texture. These variations in individual fleeces always occur most frequently in bad seasons, when food is scarce and the surroundings unfavourable.

D. **Annual Variation.**—Great as are the differences in fibres of wool growing upon the same sheep in the same year, there are also great differences in the wool of the same sheep in different years, because the wool and its character depend very largely not only on the health of the sheep but also upon climatic and other influences. The mildness or severity of the season and the plenty or scarcity of food very largely affect the character of the wool. In very severe seasons there is a tendency to a thickening of the fibres, with greater irregularity in the length of the general staple, and a greater rankness of the fleece, with undergrowth of short fibres, and a greater irregularity in the diameters of the individual fibres and the different parts of the same fibre. The general character of the wool is also affected, because from constant wetting and drying in the bad seasons the wool becomes tender and rotten, and loses its brilliancy and lustre. This may also arise from the fact that a part of the suint or yoke is soluble in water, and in very wet seasons much of this is dissolved out. When examined under the microscope, the individual fibres are found to be injured in their structure by the want of proper nourishment and the deficiency in the natural suint or grease, a large part of which is soluble in

water, and when removed leaves the fibres dry and hask. Of course, amongst well-tended flocks these variations are reduced to a minimum, because they are supplied with suitable shelters from the storms, and fed artificially when there is a scarcity of pasture; but amongst those sheep which occupy less favoured positions, and are more dependent upon the character of the seasons for everything wkich they require, there is a much larger variation than would really be suspected without actual observation. Those who have cased or classified considerable quantities of the highland and mountain wools know how much lower is the general classification of the fleeces in stormy than mild seasons. There is a marked variation in the structure of the scales on the surface of the wool fibres from the same sheep in different years. Whatever tends to improve the general health and condition of the sheep increases the number of the serrations and causes them to be more regular.

These last observations relate to the variation which arises in the character of the wool where the sheep remains really stationary, and the greatest variation which occurs in its surrounding conditions arises from the difference in the meteorological changes taking place at its area of residence; but there are also very important variations which are introduced into the character of the wool when the same sheep is removed from one district to another. These changes may be considered under our next division.

E. **Change by Environment.**—These variations are the result of an entire change in the surroundings or environment of the sheep both in regard to climate and food. In some instances this variation may be only slight, because the conditions only vary in a small degree; but as a rule, if there is very great difference in the character of

the two districts, there will be equal results produced in the character of the wool. When a mountain sheep is brought down into the valleys it soon begins to change the character of its fleece. The long coarse hair which is mixed with coarser parts of the fleece of wool diminishes in number, and the general character of the wool becomes finer: even the general appearance of the sheep changes, since it requires less exertion in the procuring of its food, and therefore accumulates more flesh and of a finer quality.

This change in the character of the wool and even of the sheep themselves, by simple removal from one district to another, was very distinctly marked in the early history of sheep-farming in New South Wales. As the colony had no native sheep, a flock was introduced from Bengal, which was the nearest place where they were found, and which had regular communication with the colony. The sheep first imported, however, were of a very poor class: they are described as having "large heads, with Roman noses and slouch ears. They were extremely narrow in the chest, with plain and narrow shoulders; high curved backs; tremendously long legs, and covered with a coarse hairy fleece."[1] This was an accumulation of bad qualities which seemed to augur ill for the future of the sheep in Australia, since they were almost more like goats than sheep. The change, however, in the surroundings and food of the sheep worked wonders, and the alteration which was produced seemed to be an exception to the generally recognised fundamental principles of the paramount influence of blood and breed, and showed how largely even these two important considerations might be modified by the far more subsidiary

[1] Widowson's *Van Diemen's Land*, p. 142.

ones of soil and climate. In two or three years the sheep were scarcely recognisable: even the general form of the sheep was improved, and the hairy covering was replaced by a comparatively fine woolly fleece. The individual fibres of which the fleece is composed improve in the same way as the general character of the fleece. The uniformity in the length and diameter, and the silkiness and general tendency to curl becomes greater, while the scales on the surface become more numerous. The serrations also become more distinct, and thus the wool is rendered better adapted for textile purposes.

When the Merino was introduced, the third or fourth cross with these earlier sheep produced an animal whose fleece was equal to that of the pure Merino in Europe, and indeed the wool of the pure breed seemed to improve as much as that of the primitive sheep had done.

We have already mentioned the remarkable case of the Angora goats which, when removed from their native district in Asia Minor, where they yield the long lustrous Mohair, to other climates, immediately alter the character of the fleece, so much so that for a considerable length of time it was thought that they could not be cultivated elsewhere; but recent experience has shown that when these creatures are introduced into favourable situations, such as Cape Colony and the United States, and crossed with native goats, they not only yield an equal quality of fibre, but are actually much improved by the care and attention of scientific farming as compared with oriental neglect. In the same way, when other sheep are introduced into the Angora district the fibre of the fleece increases in length and lustre: indeed the district conditions seem peculiarly favourable to the growth of long silky hair, for it even extends to the cats, rabbits, and rats of

the district, and when removed these also tend to deteriorate.

This alteration of the character of the wool with change of conditions is even more strikingly illustrated in its deterioration when sheep yielding good and fine wool are neglected or permitted to run wild. The general quality of the fleece deteriorates at once, the tendency to produce hair and coarse wool increases, and the general symmetry of the sheep becomes lost and reverts back to the ungainly form of its primitive ancestors.

The same causes which affect the character of the wool in the same sheep when removed to other conditions are also at work in varying the character of the wools on the various sheep which are found scattered over different parts of the earth's surface; and in addition to these we have the variety of race which has probably resulted from the continuous operation of these external forces. These peculiarities will be best considered under our next division, viz. :—

F. **Variation by Climate.**—The variation in fibres from different sheep and grown in different countries.

As we have already seen, the wool fibre is liable to great variation and modification in structure, until on the one hand it passes into true hair, and on the other into such unlike structures as the feathers of birds. It is indeed very difficult to find any classification of the sheep which in all its varieties can be based upon any general likeness in the structure of the wool fibre, in the same way that fishes have been classified according to the nature of their scales. We may, however, generally consider them as ranged into three classes.

(1) Those sheep the fibres of whose wool most nearly approach to a true hair, where we have the nature of the

epidermal covering scales most horny and attached most firmly to the cortical structure. This class includes all the lustrous varieties of wool, besides Alpaca and Mohair.

(2) Those where, although the epidermal scales are more numerous than in the first class, they are less horny in structure and less adherent to the cortical substance of the fibre—that is to say, in proportion to their length. This class includes most of the middle woolled sheep and half-breds.

(3) Those where the characteristics of a true wool are most highly developed—where we have greatest suppleness of fibre, fineness of texture, and where the epidermal scales are attached to the cortical substance through the smallest part of their length. This class includes the wools of all the finest classes of sheep, such as the Merino and crosses with it.

Of course, as we shall shortly see, it is quite impossible to draw any distinct line of demarcation between these various classes, as they insensibly shade into each other, and we can only see the real differences when we come to examine the fibres which stand furthest apart in the different classes. I am, however, of opinion that along with the mechanical differences there is also a chemical difference indicated in these variations, and one which we shall afterwards see influences the relation of colouring matters to them.

Alpaca.—(1) Amongst the fibres most nearly allied to a true hair we must class Alpaca, and indeed, strange as it may appear to some, Mohair is far more allied to wool than this fibre, although we call it a hair. The fibres obtained from the allied animals, the Llama and Vicugna, are more like wool, and are less cultivated than the Alpaca (*Auchenia paco*). When examined under the microscope

many of the fibres of Alpaca indicate not only an external but an internal likeness to true hairs also, for there is in a large number of the fibres, especially the coloured ones, a distinct central portion composed of large nucleated cells with considerable quantities of coloured pigment. When the external surface of the fibre is examined, like an ordinary hair the scales are scarcely visible, and only reveal themselves by the trans-

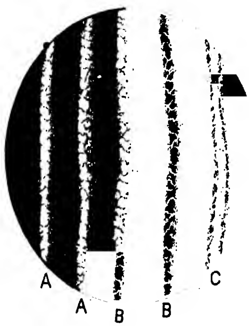


FIG. 57.—Fibres of Alpaca. × 260 diameters.

A. Fibres of Ariquepa Alpaca. B. Fibres of Chala Alpaca. C. Fibre of Brown Alpaca.

verse and anastomosing lines which indicate the edges of the plates. When treated with a caustic alkali, sufficiently strong to remove all the fatty matter from the surface and beneath the free edges of the scales, they are more distinctly seen, and Fig. 57 gives an illustration of a number of these fibres from different districts: A, is Arequipa Alpaca; B, Chala Alpaca; and C, Brown Alpaca. When we examine the nature of the surface of the Alpaca fibre, we notice the very great brilliancy of the surface of the

epidermal scales, which, when perfectly clean and viewed with light reflected from the surface, shine almost like polished metal. When carefully compared with the scales on the surface of a true wool, the Alpaca scales are more robust, and dense, and wanting in translucency, having a sort of ivory consistency rather than a glassy appearance. This is of considerable importance to note, because it lies at the root of some of the difficulties which are experienced in the dyeing of Alpaca as compared with the truer wools, and is one of the causes which render it more difficult to fix the colour permanently upon Alpaca. There are, of course, great varieties in the appearance of fibres even from the same animal, and greater still in different animals; but as a rule we may assume that the structure of the Alpaca fibre as a whole is denser than the truer wool fibres, and offers a greater resistance to the penetration of dyes, more especially those which require the aid of a mordant to fix them.

Nearly allied to the Alpaca fibre are many of the coarser wools which are derived from the mountainous districts of Asia, although these are frequently much more defaced by the prevalence of long coarse and kempy hairs than the Alpaca. We may mention a few of them, although they are very numerous, but these will serve as examples to illustrate what we mean. In the grey Vicaneer and yellow Pacpathian wools we have large horny scales which very closely resemble the Alpaca scales, but they are not quite so regular and not quite so lustrous, though they differ very much in this respect. These wools are, however, always defaced by the coarse hairs which grow along with them, and mixed with a finer undergrowth of a much more true wool. Fig. 58 gives an illustration of the yellow Pacpathian, where we see fibres

of all these different kinds. The fibres A and E will be seen closely to resemble Alpaca in general appearance, and in the structure of the epidermal scales. C is a coarse hair with large rough scales and dark pigment cells, while B and D are fibres which exhibit all the characteristics of fine true wool. The same general features which are found in these wools extend to all the coarser wools of

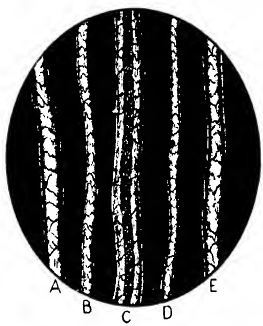


FIG. 58.—Fibres of Pacpathian Wool. × 75 diameters.

A and E. Fibres of coarse wool closely resembling alpaca.
B and D. Fine fibres with all the characteristics of true wool.
C. Coarse hair with central core of dark pigment cells.

Asia and Northern Europe, but when we pass into the east of Asia we come in contact with another breed of sheep, where we have all the characteristics of true wool exaggerated in large coarse fibres. In this Chinese wool we have the surface covered with a series of plates which possess high lustre, but where the fibre seems to be composed of distinct segments, the various scales being in each instance not distinct but coalesced into separate rings, which fit into each other like cups or crowns, and the

serrations being large and distinct. A few fibres of this wool are exhibited in Fig. 59. At A we have one of the finer fibres where the cup-like structure is distinctly visible, but with serrated scale edges. In B and C we have coarse large-scaled fibres, and in D a coarse fibre exhibiting a finer structure at the upper end. The same general remarks which apply to the ordinary run of the coarser wools in Asia also apply to the Russian and other nomadic wools of Northern Europe. Some of the wools of Northern India are very similar, as may be seen in Fig. 60, where the large ring-like scales are very marked. We have amongst them all classes of fibre, varying from hair which cannot be distinguished from the goat's down to a fine short wool. In many districts within recent years very great improvements have been introduced; indeed some of the very finest and purest Merino wools are exported from Russia.

Mohair.—When we come to Mohair, the fleece of the Angora goat, we have another distinct step towards true wool. The scales become less numerous than in the Alpaca, but are more decided and show a more definite edge, and we find a much greater variation in the general structure of the surface of the fibre when taken from different parts of the same fleece. The illustrations given in Fig. 61 are taken from a pure-bred ram and magnified 200 diameters. The fibres were very fine and wavy, and of a pure, transparent, lustrous white. A and D are fibres taken from the finest part of the fleece, while B and C are from the britch. The length of some of the fibres was nearly twelve inches, and the diameters varied from $\frac{1}{850}$ of an inch to $\frac{1}{1520}$ of an inch. In the coarser fibres the scales are the largest, and seem to be more irregularly disposed on the surface, and in the finer

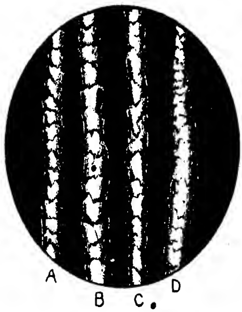


FIG. 59.—Fibres of Chinese Wool. × 75 diameters.

A. Fibre most closely resembling true wool.
B and C. Coarse fibres from the flank of the sheep.
D. Coarse fibre running into fine at the extremity.

FIG. 60.—Fibres of Indian Wool (Cashmere). × 150 diameters.

fibres the scales and general structure seem to become very closely allied to the longer varieties of deep-grown lustrous wool. These finer fibres may with advantage be compared with those taken from a well-bred Lincoln hog given in Fig. 51, and the general likeness will be easily recognised. In all the deep-grown English wools we have the same general type as given here, the only variation being that as we approach the finer character of staple we distinctly

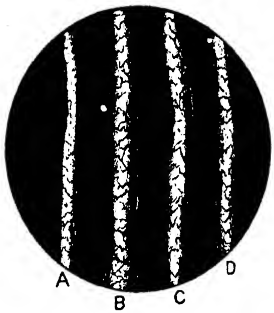


FIG. 61.—Fibres of Mohair. × 200 diameters.

A and D. Fibres taken from the finest part of the fleece.
B and C. Coarse fibres with large irregular scales.

increase the tendency to greater distinctness of the covering scales and greater number of them. Thus in the fine-bred Leicesters we have them generally more numerous than in Lincoln wools, and more so again in the best deep-grown Irish and Northumberland. They may also be compared with Fig. 62, which represents fibres from a Leicester hog magnified 225 diameters, and with Fig. 63, which gives the appearance of fibres from a Roscommon sheep magnified 150 diameters. The author, however, has seen in more

FIG. 62.—Fibres of Leicester Wool. × 225 diameters.

FIG. 63.—Fibres of Irish Wool (Roscommon). × 150 diameters.

than one sample of pure-bred Leicester fibres which could scarcely be distinguished from some of the longer Australian wools, although not so fine in the staple; and this may serve to mark the persistence of the new Leicester type even when crossed with the Merino after a few generations. Closely allied to the Mohair is the fine Cashmere wool of India, which is the produce of a goat which abounds in the mountains of Tibet. The hair is even longer than that of the Angora goat, some specimens reaching even 16 inches in length, but it is not so curly, and indeed in many specimens has hardly any curl whatever. The finest parts of the fleece only are used, of which a single goat does not yield often more than 3 ozs., and the produce of ten goats is required for a single shawl not more than 1½ yards square. The surface of the fibres, which are even more like true hair than the Mohair, is not, however, so brilliant in the samples which I have seen, and the scales are rather more numerous, and in many places so thin as almost to be invisible or only revealed by the very faintest surface markings.

A mixed breed produced by crossing the Tibet with the Angora goat has been found to possess the most valuable properties by increasing the best properties of each of the parent stock, and also the abundance of the best fibre, but even in this cross the peculiar goat-like arrangement of the scales is still visible.

When we come to deal with

(2) The middle class of wools, where we have the artificial introduction of fresh blood for the special purpose of modification of the wool, so as to obtain the lustre and length of the deep-grown with the softness and fineness of the Southdowns and other short-woolled sheep, we can see at once the influence of this crossing in the structure of the fibre.

The author was particularly struck with this in a sample of Mohair which he examined some time ago, and which was marked "first cross, half-bred wether." This example, which is figured in Fig. 64, may be compared with the pure Mohair given in Fig. 61, and the difference will be at once apparent. This difference is specially noticeable in the coarser fibres C and D, where the scales are much more serrated at the edges. A and B closely resemble wool.

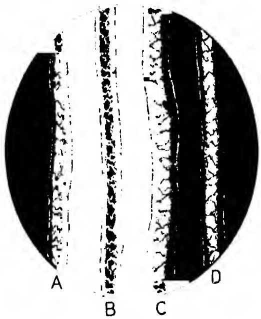


FIG. 64.—Fibres of Half-Bred-Mohair. × 200 diameters.
A and B. Fine fibres closely resembling true wool.
C and D. Coarse fibre showing the serrated edges of the scales.

The author does not know what class of animal the Angora was crossed with, but we see at once the much more close approximation of the fibres to true wool than even in the finest fibres of the pure Mohair. The general length of the fibres was not more than 4 inches, and the average diameter not more than $\frac{1}{1800}$ of an inch, so that the author thinks the cross must have been with some pure, well-bred goat which is not native to America, from whence he received the sample. It is probable that it was a

Cashmere goat or some derivation. In the half-bred English wools we have another step towards the perfection of the true wool fibre, and this increases just in proportion as we advance towards the pure Southdown. There is a continual tendency to shorten the length of the wool, but to increase all its most typical qualities by an increase in the tendency to curl, in the number of serrations or scales to the inch, and the looseness with which they are attached to the cortical substance, as well as a decrease in the average diameter of the fibres.

All these properties vary with the degree of pureness in the breed of the sheep, and the degree of care to which they have been subjected. Although the Merinos have ceased to exist as a separate breed in England, the influence which they have exerted on the Southdowns is quite perceptible in the general structure of many of the fibres, which in the finest classes closely resemble the pure Merino.

Southdown Wool.—Fig. 65 may be taken as a fair illustration of pure Southdown wool, where we have the typical characteristics of this class well exhibited. All the fibres, A, B, C, and D are splendid examples of this famous wool. The scales are transparent and loose with fine serrated edges, and a tendency to run into each other so as in many parts to form a series of ring-shaped scales like the coarser Chinese wool, only of course very much finer. The colour is pearly white, and the fibres quite transparent, so that the internal structure scarcely shows under any illumination. If these fibres are magnified 225 diameters, as in Fig. 66, so that the scales are clearly seen, the close setting of the scales as compared with the diameter being marked; and this is also seen in a closely allied wool, the Oxford Down, which is seen in Fig. 67, magnified 300 diameters;

FIG. 65. Fibres of Southdown Wool. × 230 diameters.

A and B. Fibres taken from the shoulder. C and D. Fibres taken from the flanks.

FIG. 66.—Fibres of Southdown Wool. × 225 diameters.

and this may also be compared with the fibres of Cheviot wool given in Fig. 68, where the difference in the arrangement of the scales is very noticeable when magnified 125 diameters. This class of wool approaches very closely to the

Merino Wool.—(3) The highest type of wool fibre, where we have all the best qualities exhibited. These high-class fibres are all the result of the cultivation of

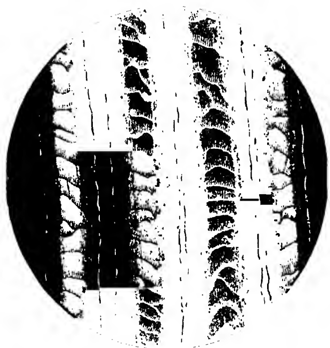


FIG. 67.—Fibres of Oxford Down Wool. × 300 diameters.

the Merino sheep, and for the longer wools of its judicious crossing with the new Leicester and other first-class long-woolled breeds, so as to increase the length of the staple and render the wool fit for combing purposes as well as for carding. We need only give two illustrations of these fibres. The first, Fig. 69, where we have a number of fibres of the finest American Merino, which even exceed in beauty and fineness of fibre the best Saxony or Australian wool. Some of these fibres were not

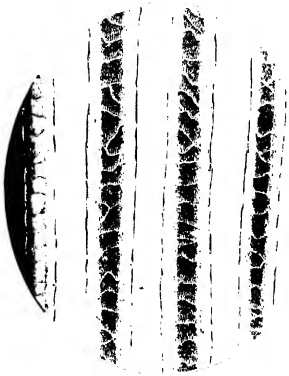


FIG. 68.—Fibres of Cheviot Wool. × 125 diameters.

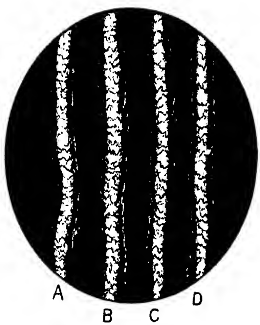


FIG. 69.—Fibres of Pure Merino Wool (American). × 300 diameters.

Showing the delicate serrated edges of the epidermal scales and their great regularity.

more than $\frac{1}{3000}$ of an inch, and the scales so numerous that they were not further apart than half the distance of the diameter of the fibre, so that these must have been about 6000 to the inch. The whole structure of the fibre was so beautifully delicate and silvery that it was quite a picture to look at. The fibres A and B are the perfection of wool, and even C and D, from the coarser part of the

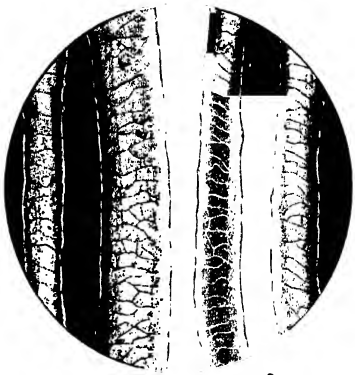


FIG. 70.—Fibres of Pure American Merino Wool. × 300 diameters.

fleece, leave nothing to be desired. The length of the fibre was about 2 inches. This was the finest sample of wool the author ever saw. These fibres when magnified 300 diameters, as seen in Fig. 70, show how fine and delicate the scales are, and these may be compared with the fibres of French Rambouillet Merino shown in Fig. 71 and with German Saxony Merino shown in Fig. 72.

Cross-Bred Wool.—When we cross these fine-fibred wools with the long-woolled breed of sheep we increase the

FIG. 71.—Fibres of Pure French Merino Wool. × 240 diameters.

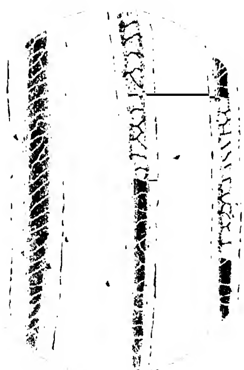


FIG. 72.—Fibres of Pure German Merino Wool (Saxony). × 225 diameters.

lustre of the fibre, because we increase the size of the reflecting surfaces, which diminishes the dispersion of the light, but we also increase the diameter of the fibres and their general coarseness. We gain, however, the length of staple which enables these fine wools to be used for worsted spinning; and at the present time, such has been the improvement in these wools derived from some of our colonies, that all classes of English bright wools can now be

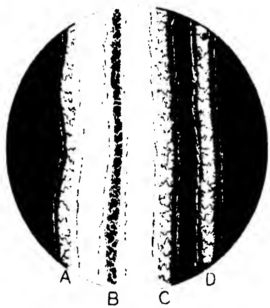


FIG. 73.—Fibres of Australian Wool (Botany). × 230 diameters.
A and B. Fibres taken from the best part of the fleece.
C and D. Fibres taken from the coarser parts.

replaced by some of these long-woolled foreign varieties, and even where not replaced the yarns are much improved by an admixture with them.

Fig. 73 gives a typical illustration of this class of wool—the Leicester Botany. Here we have the curl and softness of the Merino united with the length and lustre of the best deep-grown English wool. The diameter of the fibres is reduced from an average of about $\frac{1}{600}$ of an inch, as in the pure Leicester, to $\frac{1}{1000}$ of an inch, and the number

of scales per inch also increased in about a like proportion; while, with the purity of the climate and the care and attention bestowed on the sheep, the fibres become wonderfully uniform, and the lustre bright and silvery, some of the fibres approaching in brightness even the lustre of the Mohair. These fibres are magnified 250 diameters in Fig. 74, and they may be compared with Fig. 75, which

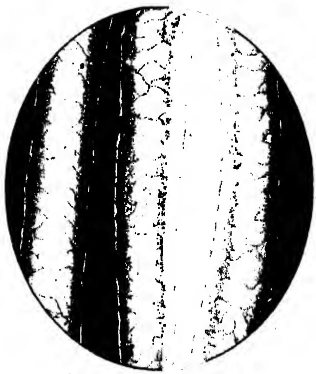


FIG. 74.—Fibres of Coarse Merino Wool crossed with Leicester. × 250 diameters.

shows fibres of Australian Merino crossed with Lincoln, in which the difference in the Leicester and Lincoln strain can be easily recognised.

Having now shortly looked at the various modifications which are introduced into the wool fibre by variation in the condition of the sheep as far as food, climate, cultivation, and race are concerned, we are now in a position to consider the last part of our inquiry, viz. :—

III.—*How far these variations in the ultimate fibre may affect its use in the manufacturing process.*

G. Mechanically.

H. Chemically.

This, of course, is really the most important part of our subject, and the one which demands our closest attention,

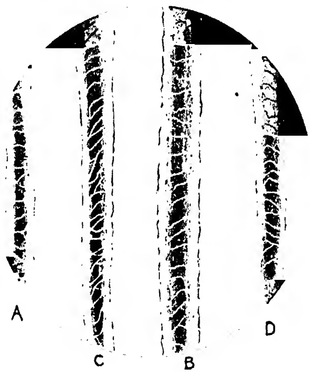


FIG. 75.—Fibres of Half-Bred Australian Wool, Merino and Lincoln. × 225 diameters.

A and B. Lincoln-like fibres. C and D. Merino-like fibres.

because it really involves any practical results which may flow out of our previous investigations. All the changes through which the raw material is passed in the manufacturing process is either mechanical or chemical, or a combination of the two, for though in some cases they cannot be separated, they are nevertheless of a different order.

G. In regard to the mechanical effect of the various

differences in the nature of the fibres with which we have to work, the author can only repeat what he said in the work on the *Structure of the Cotton Fibre*,[1] that we can only expect to arrive at better results by an intelligent adaptation of all the knowledge which we possess, both in regard to the nature of the material with which we are working and to the use of right methods in the manipulation—that is to say, methods which are founded on a correct *rationale* of the principles involved in the transforming process. All our machines and processes are only a means to an end, and the correct method of proceeding is ever to have the *end* in view from the beginning. Strange as this may appear, such is not always the case in our manufactures, and especially in those where the materials pass through many hands in different works before reaching the final stage. How often do we find the farmer, for example, quite careless in regard to the nature of the dips and washes and smears which he uses for his sheep, in utter forgetfulness of the fact that although he may gain a temporary advantage he is spoiling the wool for future use in spinning and dyeing. The manager of a very large wool-combing establishment once said to the author, "Nothing bothers us more than the ignorance and stupidity of some farmers. If they would let the wool alone, and send it to us as it grows on the sheep, we should have far less difficulties to contend with. The fibre is spoilt before it comes to us." How often in detaching the wool from the skin at the felmonger's, or even in careless sorting and packing, do we find the fibre needlessly injured, not to speak of the after-washing and drying of the wool, when temperature is guessed, and soaps and scouring solutions

[1] Bowman, *Structure of the Cotton Fibre*, Macmillan & Co., Ltd., London, 1908.

used, with an utter disregard either to the spinning, or manufacturing, or dyeing. How often do we find in the spinning of the yarn an utter want of proper adaptation, either in the machines used for the raw material which is being worked, or, what is quite as bad, in the wrong setting of the various parts of the machine to do the work even when they are capable of it when rightly managed. We know that the exigencies of trade have often compelled manufacturers to endeavour to use their machines for purposes for which they were not strictly designed by the greater variety and character of yarns which are now required; but we also know that until recently, at any rate, there has been less attention paid in the worsted than in the cotton trade to the exact adaptation of every process and every machine to the exact raw material which it was designed to work, and the machines themselves were less automatic. This is, however, now passing away and, in consequence of these defects, there have been many failures in the endeavour to produce certain results which are attainable if the right machines and the right use of them are only applied. The future of manufactures seems, like the future of scientists, to point to *specialists*, and we already see this in the fact that certain individuals and even certain districts obtain a special name, which the necessary adaptation in every respect alone can give; and it will be more so in the future, as a continually higher standard of perfection will be required. What shall we say in regard to the neglect of all consideration in the mechanical processes which is often evinced in respect to after-chemical processes, such as dyeing and finishing, where unsuitable soaps, unsuitable oils, unsuitable temperatures, both moist and dry, are frequently used, in absolute forgetfulness that the delicate fibres are afterwards intended

to receive various shades of colour, and need all the porosity of the fibre, and all the original surface lustre of the epidermal scales, if they are to give the full effect to the beauty with which they were originally endowed? Then we wonder how it is that certain goods come up wrong, or certain parts of the warp or weft are not alike, or certain shades are fugitive or change their colour, and every one concerned blames every one else in a "vicious circle."

It is beyond the scope of this work to deal with the nature of the machinery which is employed in the mechanical processes of manufacture, either in spinning or weaving, and for such information the author can only refer to such works as W. S. B. M'Laren, M.A., on *Spinning Woollen and Worsted*, in Cassell's Series of Manuals of Technology; Ashenhurst's *Treatise on Weaving*; Barlow's *History and Principles of Weaving*; and Fox's *Mechanism of Weaving*.[1] Our intention here is to treat of the principles which underlie these processes. The treatment of cotton in the process of manufacture into yarn is much more purely mechanical than that of wool, because the cotton needs no previous process of washing, which is one of the essentials previous to either worsted or woollen spinning, at any rate so far as grey yarns are concerned, and indeed all yarns which are made in the first instance from the fleece; for we know that many kinds of woollen yarn are now made from materials which, to say the least of it, possess only a very small quantity of original wool in them. No process is more important than this preliminary washing, and indeed the more attention which is paid to this part of the manufacture the better will be the results which are obtained.

[1] *Mechanism of Weaving*, T. W. Fox, M.Sc., Macmillan & Co., Ltd., London, 1907.

We have already seen how delicate is the structure of the fibre, and how easily the fine enamelled surface of the epidermal scales can be injured, either by too great heat in the water, or the use of alkaline leys, which remove not only all the suint and free fats which are associated with it, but also attack the fatty constituents of the structural cells, and thus not only tend to render the fibre hard, unpliable, and hask, but also deteriorate the strength and destroy the lustre. The results of our inquiries in regard to these various points, which we have already considered in their proper places, mechanically and chemically, would lead us to the following conclusions in regard to the rules which should guide us in this preliminary cleansing of the wool:—

Rules to be followed in washing Wool

(1) Never permit the temperature of the washing liquor to exceed 130° F. for coarse free wools, or 140° F. for fine wools.

The practice of turning steam direct into the vessels which contain the wool is most reprehensible, because when the steam, in the act of condensation, comes into contact with the fibres of the wool, they may be subjected to a much higher temperature than they can stand without injury, since the mass of wool in the water prevents the free formation of currents, and thus causes one part of the liquid to be at a much higher temperature than another. The author's experiments in regard to this matter have shown that in a bowl of water and wool the temperature of the water in some parts may almost approach the boiling point, 212° F., while in other parts of the same bowl it may not be more than 90° F., or even less. The best way is to

have the water heated in a separate tank or cistern, and draw the water into the washing machines from this cistern, where the temperature can be kept comparatively constant.

(2) Nothing but perfectly neutral soaps should be used, at any rate when the wool is in any degree clean, and potash in preference to soda as the base of the soaps.

When the wool is very dirty and the grease hard and stiff, it may sometimes be necessary to use a slightly alkaline soap, and thus remove the adhering grease more rapidly, but the greatest care should be exercised to prevent the surface of the fibre from being injured. The suint, which is the natural grease of the wool, as we have already seen, is composed in the larger part of sudorate of potash, which really assists in the washing of the wool without in any way deteriorating it. The higher lustred fibres, such as alpaca and mohair, are even more sensitive to temperature and free alkali than wool, and hence in washing all fibres when lustre is important, the lowest temperature above 60° F. and the perfect neutrality of the soaps are most important, and by the process of steeping the wool before washing there is a great saving in soap as well as the recovery of a valuable residual.

(3) The less agitation and mechanical action in the form of squeezing or pressure which can be used the better.

We have already seen that when wool fibres are exposed to the action of hot water they are more liable to felt than when in the dry state, and especially when the wool is intended for worsted rather than woollen spinning, ought the greatest care to be exercised in the manipulation of the wool so as to cause the least felting action.

(4) The greatest care should be exercised in the drying of the wool, after washing, so as to prevent too high a

temperature, which should not exceed 100° to 120° F. at the most, but the lower the better.

This is also a most important matter, because if the wool is too much dried it becomes desiccated and loses its natural kindness and suppleness, and tends to become brittle. In addition to this, when unduly dry the wool fibre becomes electrified, and the fibres then are mutually repellant, so that they resist the natural order in which they should be placed by the action of the machinery, and the yarn becomes uneven and rough.

CHAPTER XIII

STRENGTH AND TESTING OF WORSTED YARNS

WHEN the process of washing is completed, it becomes necessary to determine the special character of the process of spinning which is to be adopted in order to change the fibre into yarn. Wool may be changed either into worsted or woollen yarn according to the processes to which it is subjected. These two different classes of wool threads are essentially different. Formerly it was considered a sufficient definition between the two to say that worsted was made from long wool, and woollen yarn from short wool; or the difference was frequently expressed by saying that worsted yarns were made from combed, and woollen yarns from carded wool. These distinctions were generally true, because formerly nothing but long wools could be spun into worsted, and short wools into woollen yarn, and the usual process was combing for the worsted and carding for the woollen yarns; but neither of these definitions expressed the essential difference between the two, which is really determined by the method in which the fibres are arranged in the two threads.

Classification of Yarns.—The improvements in machinery, especially in combing, have rendered it possible to comb short wools which at one time could only be

carded, and many wools are now treated by carding preparatory to combing, as well as many short wools being spun into worsted. The real difference lies not in the method of preparation, but in the difference of mechanical constraint which is put upon the fibres in the two different classes of yarn. In the worsted thread the fibres are arranged parallel to each other, and the twist which is put into the yarn is simply a general twisting of all the parallel fibres round the central axis of the thread, the longer and shorter fibres being intermixed with each other equally throughout the whole cross-section. In the woollen thread this is not the case: the parallelism of the fibres is purposely prevented, and the method employed in spinning determines that all the longer fibres shall arrange themselves more or less along the central axis of the thread, while the shorter are thrown upon the surface, so that in cross-section the longer fibres occupy the centre and the shorter the circumference. The strength of the two threads, also, in the case of the worsted thread depends more upon the strength derived from the mechanical arrangement of the fibres, and their mutual resistance to longitudinal strain derived from their parallelism and twist; while in the woollen thread it is derived from the matting and entanglement of the fibres one with another, like links in a chain, arising from the interlocking action of the epidermal scales. The characteristic of worsted yarn is therefore great smoothness and hardness of thread, while that of woollen is roughness and fulness, and the greatest perfection of each of these respective yarns is reached just in proportion as these two characteristics are most prominent. Worsted yarn is therefore best adapted to display the best strength and lustre of wool, while woollen yarn best exhibits the softness and pliability. These

respective features are easily seen when a worsted and a woollen thread are examined with a low magnifying power, such as the ordinary piece-glass used for counting the number of picks in cloth.

In the process of worsted spinning, therefore, the greater the uniformity of the fibres, both in regard to length and diameter, the greater will be the chance of arriving at the best results in the finished yarn; while in the woollen thread the same regularity will not be necessary—indeed, the highest character will be attained where there is a considerable but not too great difference in the dimensions of the separate fibres.

In all wools there are considerable differences in regard to both these dimensions, and it becomes important to see how far these differences affect the regularity and perfection of the spinning, as regards the uniformity of strength, regularity of twist, and evenness of diameter, especially in the worsted yarns, because all these desiderata are less important in the woollen thread.

It will be seen from this how very important it is that the proper class of wool be selected from which to spin the various kinds of yarn which are required in textile manufactures, because upon this suitability of the raw material will depend the success of the results in the manufactured state. Nothing indeed in the whole range of technical knowledge requires greater judgment and experience than the selection and blending of the various wools, and where this preliminary is neglected it is impossible to spin good yarn.

The counts to which wool can be spun depend upon the diameter of the fibres of the wool, because if we get less than a certain number of fibres in a cross-section of the thread, we cannot have either uniformity in the spinning

or tenacity in the yarn. The fineness of the wool differs very much in different classes of wool, but the following table, taken from Leroux's *Treatise on the Manufacture of Worsted and Carded Yarns*, will give some idea of this relation between fineness and spinning power :--

Comparison of Wools from Different Sources, with their Diameter and the Counts into which they can be spun

Sorting Number.	Wool from							Counts.	Diameter of Fibres in Decimals of an Inch.
	Silesia.	Saxony.	Australia.	Champagne.	Spain.	North of France.	Algeria.		
1	Extra fine	...	...	...	...	...	...	199·35	From ·0059
2	Superfine	Extra fine	...	...	...	...	...	159·48	
3	Fine	Superfine	Extra fine	...	...	...	...	141·76	to
4	Semi-fine.	Fine	Superfine	Extra fine	...	...	...	128·47	
5	Medium	Semi-fine	Fine	Superfine	Extra fine	...	...	115·18	·0098
6	Coarse	Medium	Semi-fine	Fine	Superfine	...	...	106·32	From ·0098
7	Very coarse	Coarse	Medium	Semi-fine	Fine	...	...	93·03	
8	...	Very coarse	Coarse	Medium	Semi-fine	Extra fine	...	84·17	to
9	...	...	Very coarse	Coarse	Medium	Superfine	...	75·31	
10	...	...	...	Very coarse	Coarse	Fine	Extra fine	62·02	·0177
11	...	...	...	...	Very coarse	Semi-fine	Superfine	48·73	From ·0177
12	...	...	...	...	...	Medium	Fine	26·58	
13	...	...	...	...	...	Coarse	Semi-fine	22·15	to
14	...	...	...	...	...	Very coarse	Medium	17·72	
15	...	...	...	...	...	...	Coarse	13·29	
16	...	...	...	...	...	...	Very coarse	8·86	·0295

The counts given in this table are the French metrical counts.

To determine the degree of regularity in the strength, counts, and twist in yarns, the author made a large series of experiments with different classes and counts of worsted yarns, under similar test conditions to those which he has already given in the work on the structure of the cotton fibre, and to these he must now call attention.

Experiments on Worsted Yarns

In making the experiments upon the strength and regularity in counts of cotton yarn, he always operated upon one wrap or lea, which is 120 yards, or $\frac{1}{7}$th part of the hank of 840 yards; and when this lea is reeled upon a reel $1\frac{1}{2}$ yard or 54 inches in diameter, it represents the average strength of 160 threads, or 80 threads on each side of the wrap subjected to tension. The worsted hank is only 560 yards, in place of 840 yards in cotton, and therefore, in order that we may compare the relative strength of worsted and cotton yarns, we must reel the worsted on a 36-inch reel in place of a 54-inch, and then the hank will consist of 7 leas of 80 yards each, in place of 120 yards in the cotton lea, while we have the same number of threads to carry the strain. This is the general method of reeling single worsted yarns, and the worsted table will stand thus:—

WORSTED TABLE

1 yard	=	1 thread		
80 yards	=	80 threads	=	1 wrap or lea
560 ,,	=	560 ,,	=	7 wraps or leas = 1 hank

The counts are determined in worsted in the same way as in cotton yarns—that is to say, that 1 hank of 1's, or 560 yards of 1's, weighs exactly 1 pound avoirdupois or

7000 grains, and 1 lea of 80 yards therefore weighs exactly 1000 grains. If, therefore, W represents the weight of the lea in grains, and C the counts of the yarn, we have—

$$C \times W = 1000$$

$$\text{therefore} \frac{1000}{C} = W$$

$$\text{and} \frac{1000}{W} = C$$

In this way we can easily determine the counts of any worsted yarn if we know the weight of 1 lea or 80 yards, or the weight of 80 yards of any yarn if we know the counts. The same table of counts and weight for any number of leas of cotton yarn will serve equally for worsted yarns, if we use the 36-inch wrap reel in place of the 54-inch, because we shall then have only 80 yards in the lea in place of 120 yards. Although the 36-inch reel is the one usually employed it is not universal, as the length sometimes varies from 1 yard up to 12 yards, and the forms of making up, leasing, and tying are endless. The following table, therefore, which appeared in the work on the structure of the cotton fibre, will be useful to worsted spinners, remembering that the length of the lea is 80 yards:—

[TABLE

TABLE OF WEIGHTS OF VARIOUS COUNTS OF WORSTED YARN

Counts.	Weight of 1 lea – 80 yds. in Grains.	Weight of 2 leas – 160 yds. in Grains.	Weight of 3 leas – 240 yds. in Grains.	Weight of 4 leas – 320 yds. in Grains.
1	1000·000	2000·000	3000·000	4000·000
2	500·000	1000·000	1500·000	2000·000
3	333·333	666·666	1000·000	1333·333
4	250·000	500·000	750·000	1000·000
5	200·000	400·000	600·000	800·000
6	166·666	333·333	499·999	666·666
7	142·857	285·714	428·571	571·428
8	125·000	250·000	375·000	500·000
9	111·111	222·222	333·333	444·444
10	100·000	200·000	300·000	400·000
11	90·909	181·818	272·727	363·636
12	83·333	166·666	250·000	333·333
13	76·923	153·846	230·769	307·692
14	71·428	142·857	214·285	285·714
15	66·666	133·333	199·999	266·666
16	62·500	125·000	187·500	250·000
17	58·823	117·647	176·470	235·294
18	55·555	111·111	166·666	222·222
19	52·631	105·263	157·894	210·526
20	50·000	100·000	150·000	200·000
21	47·619	95·238	142·857	190·476
22	45·454	90·909	136·363	181·818
23	43·478	86·956	130·434	173·913
24	41·666	83·333	124·999	166·666
25	40·000	80·000	120·000	160·000
26	38·461	76·923	115·384	153·846
27	37·037	74·074	111·111	148·148
28	35·714	71·428	107·142	142·857
29	34·482	68·965	103·447	137·931
30	33·333	66·666	99·999	133·333
31	32·258	64·516	96·774	129·032
32	31·250	62·500	93·750	125·000
33	30·303	60·606	90·909	121·212
34	29·411	58·823	88·234	117·647
35	28·571	57·142	85·713	114·285
36	27·777	55·555	83·332	111·111
37	27·027	54·054	81·081	108·108
38	26·363	52·727	79·090	105·263
39	25·641	51·282	76·923	102·564
40	25·000	50·000	75·000	100·000
41	24·390	48·780	73·170	97·560

TABLE OF WEIGHTS—*continued.*

Counts.	Weight of 1 lea = 80 yds. in Grains.	Weight of 2 leas = 160 yds. in Grains.	Weight of 3 leas = 240 yds. in Grains.	Weight of 4 leas = 320 yds. in Grains.
42	23·809	47·619	71·429	95·238
43	23·255	46·511	69·766	93·023
44	22·727	45·454	68·181	90·909
45	22·222	44·444	66·666	88·888
46	21·739	43·478	65·217	86·956
47	21·276	42·553	63·829	85·106
48	20·833	41·666	62·499	83·333
49	20·408	40·816	61·224	81·632
50	20·000	40·000	60·000	80·000
51	19·607	39·215	58·822	78·431
52	19·230	38·461	57·691	76·923
53	18·867	37·735	56·602	75·471
54	18·518	37·037	55·555	74·074
55	18·181	36·363	54·544	72·727
56	17·857	35·714	53·571	71·428
57	17·543	35·087	52·630	70·175
58	17·241	34·482	51·723	68·965
59	16·949	33·898	50·847	67·796
60	16·666	33·333	49·999	66·666
61	16·393	32·786	49·179	65·573
62	16·129	32·258	48·387	64·516
63	15·873	31·746	47·619	63·492
64	15·625	31·250	46·875	62·500
65	15·384	30·769	46·153	61·538
66	15·151	30·303	45·454	60·606
67	14·925	29·850	44·775	59·701
68	14·705	29·411	44·116	58·823
69	14·492	28·985	43·477	57·971
70	14·285	28·571	42·856	57·142
71	14·084	28·169	42·253	56·338
72	13·888	27·777	41·665	55·555
73	13·698	27·397	41·095	54·794
74	13·513	27·027	40·540	54·054
75	13·333	26·666	39·999	53·333
76	13·181	26·363	39·544	52·727
77	12·987	25·974	38·961	51·948
78	12·820	25·641	38·461	51·282
79	12·658	25·316	37·974	50·632
80	12·500	25·000	37·500	50·000
81	12·345	24·691	37·036	49·382
82	12·195	24·390	36·585	48·780
83	12·048	24·096	36·144	48·192

TABLE OF WEIGHTS—*continued.*

Counts.	Weight of 1 lea = 80 yds. in Grains.	Weight of 2 leas = 160 yds. in Grains.	Weight of 3 leas = 240 yds. in Grains.	Weight of 4 leas = 320 yds. in Grains.
84	11·904	23·809	35·713	47·619
85	11·764	23·529	35·293	47·058
86	11·627	23·255	34·882	46·511
87	11·494	22·988	34·482	45·977
88	11·363	22·727	34·090	45·454
89	11·235	22·471	33·706	44·943
90	11·111	22·222	33·333	44·444
91	10·989	21·978	32·967	43·956
92	10·869	21·739	32·608	43·478
93	10·752	21·505	32·257	43·010
94	10·638	21·276	31·914	42·553
95	10·526	21·052	31·578	42·105
96	10·416	20·833	31·249	41·666
97	10·309	20·618	30·927	41·237
98	10·204	20·408	30·612	40·816
99	10·101	20·202	30·303	40·404
100	10·000	20·000	30·000	40·000

If this table is required to be used for higher counts than 100's, it is best to double the number of leas, and then double the counts which the weight represents. Thus 8 leas of 120's will weigh 66·666 grains, which corresponds to 60's on this table, and double this number is 120's, which is the counts required. For twofold yarns, 2 leas will correspond to 4 on this table, as, for example, 2 leas of 2/40's will weigh 100 grains, which is the weight of 4 leas of single 40's. In any case it is better to use 8 leas in place of 4 leas when the yarn is above 100's, because the difference in weight between one count and the next is so small that they can only be distinguished by very accurate weighing, whereas by increasing the number of leas we increase the difference, so as to make it more readily appreciable and less liable to be mistaken for any other count.

In making the experiments on worsted yarns the same precautions and methods were used as fully described in work on the cotton fibre,[1] and the same class of machines for the work, except that the reel was 36 in place of 54 inches in diameter, and it is not, therefore, necessary to repeat them.

The room in which the operations were performed was kept at a uniform temperature by a steam stove, and all the samples of yarn were exposed in the room for twenty-four hours before testing, so as to permit them to acquire as far as possible the same conditions in regard to temperature and moisture, both of which have an effect on the strength of the yarn.

It may be noted here that strength is not of the same importance in worsted as in cotton yarn, because from the nature of the raw material and the greater strength of the wool than the cotton fibre, all worsted yarns made from sound wool, unless tendered in the process of manufacture, are amply sufficient in strength for all practical purposes.

The samples of yarn themselves were selected from various makers, and were fair averages of a large production, and not picked samples, the intention being to arrive at the degree of perfection attainable in the ordinary yarns of commerce; but all the yarns were made by spinners who have a good name in the market for their respective productions.

The experiments extended over a much wider range of counts and samples than are here recorded, but the general results were the same as given by these examples, and they were chosen only from those which are generally used

[1] Bowman, *Structure of the Cotton Fibre*, Chap. XII., Macmillan & Co., Ltd., London, 1908.

in the Bradford trade, and they may be taken as types of all other similar counts of yarn.

In all cases five experiments were made with the same thread, and four threads taken out of each sample promiscuously, and the results in the following tables may therefore, from the care taken in the experiments, be relied upon as a basis for generalisation, and they may also be taken as a fair representation of what may be expected in the degree of perfection to which ordinary good commercial yarns usually attain :—

SAMPLE A

24's Single, 8·5 turns, spun from Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	60	40·12		
	48	41·32		
	64	41·48		
	42	40·25		
	60	41·83	41·000	24·34
No. 2	52	41·20		
	60	41·00		
	40	40·38		
	64	42·00		
	60	42·12	41·340	24·18
No. 3	44	41·30		
	50	40·15		
	65	40·22		
	60	41·00		
	52	42·11	40·956	24·41
No. 4	45	41·11		
	61	42·00		
	52	42·00		
	62	41·80		
	54	40·66	41·514	24·08
	54·75		41·202	24·25

This is a good commercial yarn. The counts are $\frac{1}{4}$ of a count on the fine side. The greatest variation in strength is in No. 2, from 40 to 64 lbs. = 24 lbs., or 43 per cent of the average strength. The greatest variation in weight is in No. 3, from 40·15 to 42·11 grains, or 1·96 grains, which is about 5 per cent of the average weight.

SAMPLE B

30's Single, 9·75 turns, spun from Irish and Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	30	34·20		
	42	33·60		
	40	34·12		
	28	34·24		
	25	34·00	34·032	29·38
No. 2	38	34·50		
	36	34·12		
	40	34·20		
	44	34·15		
	26	34·11	34·216	29·22
No. 3	40	33·81		
	28	33·40		
	34	33·75		
	36	34·12		
	40	34·00	33·816	29·57
No. 4	25	33·12		
	29	33·40		
	39	33·62		
	37	33·04		
	27	33·21	33·278	30·05
	34·2		33·835	29·55

This is a good yarn. The counts are rather coarse on the average. The greatest variation in strength is in No. 2, from 26 to 44 lbs. = 18 lbs., or 53 per cent of the average strength. The greatest variation in weight is in No. 3, from 33·4 to 34·12 grains = ·72 grains, or 2·1 per cent of the average weight.

SAMPLE C

36's Single, 12 turns, spun from Irish and Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	32	26·55		
	30	27·80		
	28	27·84		
	24	27·13		
	21	27·95	27·454	36·42
No. 2	30	26·83		
	21	27·81		
	28	27·24		
	27	28·13		
	21	28·25	27·652	36·16
No. 3	32	27·50		
	30	27·83		
	22	28·12		
	25	28·12		
	30	27·90	27·894	35·85
No. 4	28	27·40		
	26	27·93		
	30	27·21		
	20	27·60		
	32	27·80	27·588	36·24
	27		27·617	36·16

A good commercial yarn. The counts are slightly on the fine side. The greatest variation in strength is in No. 4, from 20 to 32 lbs. = 12 lbs., or 44 per cent of the average strength. The greatest variation in weight is in No. 2, from 26 83 to 28·25 grains = 1·42, or 5 per cent of the average weight.

SAMPLE D

40's Single, 12·25 turns, spun from Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	25	24·87		
	24	24·88		
	20	24·31		
	28	24·90		
	20	24·25	24·642	40·58
No. 2	26	24·60		
	17	24·75		
	24	24·83		
	25	25·12		
	16	24·60	24·780	40·35
No. 3	28	24·80		
	25	25·12		
	19	25·00		
	20	25·12		
	21	24·75	24·958	40·06
No. 4	20	24·60		
	18	24·50		
	15	24·33		
	22	25·12		
	24	25·25	24·760	40·38
	21·8		24·785	40·34

This is a good yarn. The counts are about $\frac{1}{3}$ of a count on the fine side. The greatest variation in strength is in No. 2, from 16 to 26 lbs. = 10 lbs., or 41 per cent of the average strength. The greatest variation in weight is in No. 4, from 24·33 to 25·25 grains = ·92 grains, or 3 per cent of the average weight.

SAMPLE E

40's Single, 16·5 turns, spun from Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	27	25·84		
	29	25·67		
	26	25·04		
	22	24·75		
	28	25·26	25·312	39·56
No. 2	26	25·42		
	28	25·13		
	28	25·20		
	24	24·31		
	21	24·84	24·980	40·00
No. 3	25	25·12		
	28	25·31		
	27	25·00		
	22	25·43		
	29	25·12	25·196	39·68
No. 4	26	25·14		
	26	25·31		
	30	24·74		
	21	25·18		
	24	25·04	25·082	39·86
	25·8		25·142	39·77

This is a first-class yarn. The counts are rather coarse. The greatest variation in strength is in No. 4, from 21 to 30 lbs. = 9 lbs., or 35 per cent of the average strength. The greatest variation in weight is in No. 2, from 24·31 to 25·42 grains = 1·11 grains, or 4·4 per cent of the average weight.

SAMPLE F

50's Single, 17·22 turns, spun from Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	21	20·13		
	19	20·81		
	20	20·21		
	19	21·01		
	20	21·41	20·720	48·26
No. 2	22	20·01		
	21	20·31		
	18	20·13		
	20	20·34		
	21	20·53	20·264	19·34
No. 3	18	20·31		
	17	19·85		
	21	19·75		
	20	20·12		
	22	20·00	20·006	50·00
No. 4	23	20·10		
	20	20·31		
	18	20·00		
	21	19·75		
	20	19·81	19·991	50·00
	20·2		20·21	49·40

This is a very good yarn. The counts are heavy rather more than ½ a count. The greatest variation in strength is in No. 3, from 17 to 24 lbs. = 7 lbs., or 34 per cent of the average strength. The greatest variation in weight is in Nos. 3 and 4, from 19·75 to 20·31 grains = ·56 grains, or 2·7 per cent of the average weight.

SAMPLE G

60's Single, 15·37 turns, spun from Botany Merino Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	16	16·84		
	16	17·24		
	15	16·93		
	17	17·04		
	16	17·00	17·010	58·78
No. 2	16	16·61		
	13	16·51		
	17	16·40		
	14	17·10		
	16	16·64	16·658	60·03
No. 3	14	16·60		
	15	16·31		
	17	16·40		
	17	16·61		
	12	16·25	16·140	60·82
No. 4	16	17·14		
	15	16·84		
	14	16·80		
	17	17·00		
	17	17·14	16·984	58·88
	15·5		16·773	59·63

This is a first-class yarn. The counts are on the coarse side. The greatest variation in strength is in No. 3, from 12 to 17 lbs. = 5 lbs., or 33 per cent of the average strength. The greatest variation in weight is in No. 1, from 16·84 to 17·24 grains = ·4 grains, or 2·4 per cent of the average weight.

SAMPLE H

70's Single, 17·93 turns, spun from Botany Merino Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	10	14·58		
	11	15·12		
	10	14·93		
	9	15·30		
	10	14·75	14·936	66·92
No. 2	6	13·42		
	9	13·85		
	11	14·12		
	10	14·14		
	8	13·80	13·866	72·11
No. 3	12	14·21		
	10	14·36		
	8	13·88		
	11	14·41		
	10	14·36	14·244	70·20
No. 4	13	14·34		
	12	14·21		
	9	14·00		
	8	14·12		
	13	15·18	14·370	69·58
	10		14·354	69·71

This is a first-class yarn. The counts are rather coarse. The greatest variation in strength is in No. 2, from 6 to 11 lbs. = 5 lbs., or 50 per cent of the average strength. The same variation occurs in No. 4, from 8 to 13 lbs. The greatest variation in weight is in No. 4, from 14·00 to 15·18 grains = 1·18 grains, or 8 per cent of the average weight.

SAMPLE I

80's Single, 18·71 turns, spun from Botany Merino Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	8	12·84		
	10	13·12		
	11	13·00		
	9	12·50		
	10	12·14	12·720	78·61
No. 2	8	13·12		
	9	13·41		
	10	12·82		
	10	13·01		
	9	13·40	13·152	76·02
No. 3	11	12·42		
	12	12·63		
	9	12·75		
	10	12·31		
	8	12·21	12·461	80·23
No. 4	10	12·33		
	10	12·52		
	9	12·48		
	10	12·56		
	7	12·84	12·546	79·70
	9·5		12·720	78·64

This is a first-class yarn. The counts are coarse, and vary considerably between Nos. 2 and 3 = 4·2 counts. The greatest variation in strength is in No. 3, from 8 to 12 lbs. = 4 lbs., or 41 per cent of the average strength. The greatest variation in weight is in No. 1, from 12·14 to 13·12 grains = ·98 grains, or 7 per cent of the average weight.

SAMPLE J

Twofold 30's, 11 turns, spun from Irish and Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	140	66·70		
	144	66·82		
	138	66·67		
	142	66·93		
	140	66·82	66·788	14·97
No. 2	146	66·80		
	137	66·71		
	135	66·54		
	140	66·80		
	143	66·20	66·610	15·00
No. 3	144	66·70		
	138	66·50		
	140	66·83		
	136	66·54		
	138	66·31	66·576	15·02
No. 4	140	66·24		
	141	66·36		
	136	66·80		
	142	66·75		
	140	66·51	66·532	15·03
	140		66·626	15·00

This is a good commercial yarn, and the counts are correct. The greatest variation in strength is in No. 2, from 135 to 146 lbs. = 11 lbs., or 8 per cent of the average strength. The greatest variation in weight is in No. 2, from 66·2 to 66·8 grains = ·6 grains, or ·9 per cent of the average weight.

SAMPLE K

Twofold 36's, 13 turns, spun from Irish and Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	124	55·94		
	130	55·60		
	122	55·21		
	124	55·62		
	124	55·64	55·602	17·98
No. 2	128	55·80		
	132	55·76		
	125	55·24		
	127	55·40		
	124	55·35	55·510	18·00
No. 3	126	55·40		
	127	55·33		
	130	55·61		
	131	55·70		
	122	55·50	55·508	18·00
No. 4	124	55·50		
	126	55·62		
	124	55·40		
	130	55·43		
	127	55·70	55·530	18·00
	126·3		55·537	17·99

This is a good yarn. The counts are correct. The greatest variation in strength is in No. 2, from 124 to 132 lbs. = 8 lbs., or 6·2 per cent of the average strength; the same variation occurs in No. 3, from 122 to 130 lbs. The greatest variation in weight is in No. 1, from 55·21 to 55·94 grains = ·73 grains, or 1·3 per cent of the average weight.

SAMPLE L

Twofold 40's, 14 turns, spun from Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	90	50·25		
	100	50·14		
	95	49·73		
	99	50·00		
	100	49·71	49·966	20·00
No. 2	95	50·12		
	98	49·80		
	100	49·87		
	96	50·00		
	100	50·14	49·986	20·00
No. 3	99	50·23		
	100	50·40		
	100	49·75		
	94	49·66		
	95	50·00	50·008	20·00
No. 4	93	50·40		
	95	49·80		
	95	49·60		
	100	49·75		
	88	50·20	49·950	20·00
	96·6		49·975	20·00

This is a first-class yarn. The counts are correct. The greatest variation in strength is in No. 4, from 88 to 100 lbs. = 12 lbs., or 12·5 per cent of the average strength. The greatest variation in weight is in No. 4, from 49·6 to 50·4 grains = ·8 grains, or 1·6 per cent of the average weight.

SAMPLE M

Twofold 40's, 12·2 turns, spun from Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	93	50·14		
	95	50·10		
	100	49·73		
	92	49·50		
	90	49·75	49·904	20·00
No. 2	94	49·80		
	95	49·75		
	96	50·12		
	98	50·15		
	95	49·83	49·930	20·00
No. 3	99	50·00		
	97	50·14		
	99	50·38		
	96	49·73		
	95	50·10	50·070	20·00
No. 4	99	50·30		
	100	49·75		
	95	49·95		
	95	50·13		
	101	49·87	50·000	20·00
	96·2		49·976	20·00

This is a first-class yarn. The counts are quite correct. The greatest variation in strength is in No. 1, from 90 to 100 lbs. = 10 lbs., or 10·4 per cent of the average strength. The greatest variation in weight is in No. 1, from 49·5 to 50·4 grains = ·9 grains, or 1·8 per cent of the average weight.

SAMPLE N

Twofold 50's, 15·3 turns, spun from Leicester Botany Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	65	40·12		
	70	40·00		
	71	39·80		
	64	40·12		
	63	40·00	40·000	25·00
No. 2	70	39·84		
	66	39·90		
	60	39·75		
	65	40·12		
	68	40·21	39·961	25·00
No. 3	69	40·12		
	68	39·81		
	70	39·90		
	70	40·24		
	66	40·00	40·014	25·00
No. 4	65	40·21		
	70	40·10		
	72	40·14		
	74	40·30		
	71	39·75	40·100	24·94
	67·8		40·019	24·98

A first-class yarn. The counts are correct. The greatest variation in strength is in No. 3, from 60 to 70 lbs. = 10 lbs., or 14·7 per cent of the average strength. The greatest variation in weight is in No. 4, from 39·75 to 40·3 grains = ·55 grains, or 1·3 per cent of the average weight.

SAMPLE O

Twofold 60's, 19·6 turns, spun from Botany Merino Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	55	34·12		
	58	33·21		
	54	33·75		
	57	33·30		
	52	33·22	33·520	29·83
No. 2	50	33·14		
	54	32·86		
	52	32·91		
	58	32·88		
	50	33·20	32·998	30·30
No. 3	48	33·20		
	55	33·12		
	57	33·40		
	50	32·81		
	56	32·75	33·062	30·24
No. 4	51	33·15		
	58	32·86		
	58	32·94		
	50	33·00		
	49	32·91	32·972	30·32
	53·75		33·138	30·17

This is a first-class yarn. The counts are almost correct. The greatest variation in strength is in No. 4, from 49 to 58 lbs. = 9 lbs., or 16·6 per cent of the average strength. The greatest variation in weight is in No. 1, from 33·21 to 34·12 grains = ·91 grains, or 2·7 per cent of the average weight.

SAMPLE P

Twofold 70's, 23·3 turns, spun from Botany Merino Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	44	28·62		
	40	28·32		
	46	28·53		
	38	28·34		
	48	28·51	28·464	35·13
No. 2	40	28·75		
	44	28·55		
	36	28·62		
	45	28·44		
	42	28·38	28·548	35·03
No. 3	37	28·88		
	38	28·62		
	40	28·31		
	44	28·35		
	39	28·44	28·520	35·06
No. 4	42	28·77		
	48	28·82		
	47	28·55		
	39	28·62		
	42	28·50	28·652	34·91
	41·95		28·546	35·03

This is a first-class yarn. The counts are correct. The greatest variation in strength is in No. 1, from 38 to 48 lbs. = 10 lbs., or 23·8 per cent of the average strength. The greatest variation in weight is in No. 3, from 28·31 to 28·88 grains = ·57 grains, or 2 per cent of the average weight.

SAMPLE Q

Twofold 80's, 28·8 turns, spun from Botany Merino Wool.

Number of Experiments.	Breaking Weight per lea in lbs.	Weight in Grains.	Average Weight.	Counts.
No. 1	40	25·12		
	38	24·88		
	42	24·90		
	36	25·10		
	40	25·00	25·000	40·00
No. 2	36	25·00		
	38	24·87		
	35	24·82		
	40	25·14		
	41	24·90	24·946	40·08
No. 3	35	25·12		
	40	24·80		
	40	24·95		
	42	24·90		
	36	25·20	24·994	40·00
No. 4	38	24·80		
	40	25·14		
	41	25·25		
	34	24·75		
	35	24·88	24·964	40·05
	38·35		24·976	40·03

This is a first-class yarn. The counts are correct. The greatest variation in strength is in No. 3, from 35 to 42 lbs. = 7 lbs., or 18 per cent of the average strength. The greatest variation in weight is in No. 4, from 24·75 to 25·25 grains = ·5 grains, or 2 per cent of the average weight.

In looking at the general results obtained from these experiments, we are struck with the great variation in the strength of the single yarns, ranging from 33 per cent in sample G to 53 per cent in sample B. The average variation in the whole of the samples is 42·1 per cent. The variation in counts is very much less, viz. from 2 per cent in sample B to 8 per cent in sample H. When compared with the results of similar counts in single cotton yarns the worsted yarns are very much more variable, since cotton yarn varies in strength only from about 7 to 22 per cent, while the variation in weight is from 2 to 10 per cent, which is very similar to worsted yarn. No doubt the great variation in the strength of the single worsted yarn as compared with cotton arises from the fact that the samples of single cotton yarn tested were all twist yarns and not weft, while the worsted yarns have much less proportionate twist, and so correspond with weft yarns. We may also note that in most of the worsted yarns, except those spun from the finest Botany, there is a much greater variation in the size and elasticity of the component fibres, which causes the various parts of the thread to resist the torsion unequally, and thus force the twist, even when regularly put in by the machine, to adjust itself unequally in the final equilibrium which takes place in the thread.

When we examine the twofold yarns we find less variation in the strength, but still more than we should have expected in twofold yarns. The variation is from 6·2 per cent in sample K to 23·8 per cent in sample P. The average variation is 13·8 per cent, and we notice it increases as the counts become finer. The variation in counts is very small, only 1·6 per cent on the average—varying from less than 1 per cent in sample J to 2·7 per cent in sample O. When compared with the average strength of

similar twofold cotton yarns the variation in strength is still more marked, but there is not so great a difference as in the single yarns. Twofold cotton yarns vary in strength from about 8 to 19 per cent, and in counts from $1\frac{1}{2}$ per cent to about 8 per cent.

Undoubtedly the great cause of the irregularity in strength is the unevenness with which the twist is finally distributed in the thread, and this is much greater than any one who has not examined the subject would think possible. Of course, as in the case of single cotton yarns, it is very difficult to test the regularity in twist in single worsted yarns, because, if we take any length to test beyond a few inches which cover the length of the staple, the yarn will not sustain itself until the twist is determined. We can, however, easily see the great variation by a casual examination of the yarn with a small magnifying glass, and then our wonder is not that the yarn is so irregular in strength, but that it is not even more so than our experiments prove.

To determine the regularity in twist in twofold yarns is a comparatively easy matter, and in doing so the same machine was used as was employed in testing the cotton yarns, and the testing was done under similar conditions, 5 inches being taken as the standard in the second column, and 1 inch in the fourth column. The same letters also were used in the twofold samples which denote the same sample when the yarn is tested for strength, so that any further comparisons which may be required may be easily made from the data which the experiments furnish. Thus, sample J in the twofold, tested for twist, is the same yarn as sample J which was tested for strength and regularity of counts in the former tables.

These tables might have been very much extended by

giving those founded upon experiments made with other counts and classes of yarn. This would have much extended the work, and for our present purpose it is best to confine it to the range of yarns which are mostly in use in Bradford and the neighbourhood. The experiments, however, extended over a much wider range, and exhibited some very interesting results. For example, it was found that in low slack-twisted carpet yarns the variation from the theoretical twist was on the average not greater than in some of the finer yarns—a result which was hardly anticipated; also the variation was not so great in slack-twisted as in hard-twisted yarns, because in the slack-twisted yarns the strain put upon the component fibres was less, so that in the final equilibrium the twist is more evenly distributed throughout the length of the thread.

SAMPLE J

Twofold 30's, 11 turns, spun from Irish and Leicester Botany Wool.

Number of Experiments.	Twist taken 5 Inches together.	Average Twist per Inch.	Twist taken Inch by Inch.	Average Twist per Inch.
No. 1	40		15	
	50		10	
	60		9	
	52		8	
	55	10·28	11	10·60
No. 2	56		14	
	54		12	
	42		10	
	58		7	
	59	10·76	9	10·40
No. 3	48		8	
	46		15	
	52		10	
	54		12	
	49	9·96	9	10·80
No. 4	58		9	
	44		16	
	49		11	
	56		10	
	42	9·96	10	11·20
		10·24		10·75

The greatest variation in twist taken 5 inches together occurs in No. 1 thread, from 40 to 60 turns = 20 turns, or nearly 40 per cent of the average number. The greatest variation when taken inch by inch is in No. 1 thread, from 8 to 15 turns = 7 turns, or 65 per cent of the average number. The same variation also occurs in No. 2, from 7 to 14 turns; and in No. 4, from 9 to 16 turns.

SAMPLE K

Twofold 36's, 13 turns, spun from Irish and Leicester Botany Wool.

Number of Experiments.	Twist taken 5 Inches together.	Average Twist per Inch.	Twist taken Inch by Inch.	Average Twist per Inch.
No. 1	60 68 52 64 60	12·16	13 9 11 18 12	12·60
No. 2	64 68 55 55 60	12·08	11 11 16 15 10	12·60
No. 3	64 64 58 57 48	11·64	10 15 9 14 14	12·40
No. 4	66 61 58 60 55	12·00	10 8 9 13 14	10·80
		11·98		12·1

The greatest variation in twist taken 5 inches together occurs in No. 1 thread, from 52 to 68 turns = 16 turns, or 27 per cent of the average number. The same variation occurs in No. 3, from 48 to 64 turns = 16 turns. The greatest variation when taken inch by inch occurs in No. 1 thread, from 9 to 18 turns = 9 turns, or 74 per cent of the average number.

SAMPLE L

Twofold 40's, 14 turns, spun from Leicester Botany Wool.

Number of Experiments.	Twist taken 5 Inches together.	Average Twist per Inch.	Twist taken Inch by Inch.	Average Twist per Inch.
No. 1	66		12	
	74		14	
	62		9	
	69		16	
	78	13·96	14	13·00
No. 2	80		11	
	74		10	
	65		18	
	66		15	
	69	14·16	10	12·80
No. 3	68		8	
	66		15	
	64		12	
	67		12	
	72	13·48	13	12·00
No. 4	69		15	
	74		10	
	78		18	
	68		14	
	66	14·20	13	14·00
		13·95		12·95

The greatest variation in twist when taken 5 inches together occurs in No. 1 thread, from 62 to 78 turns = 16 turns, or 23 per cent of the average number. The greatest variation when taken inch by inch is in No. 2, from 10 to 18 turns = 8 turns, or 61 per cent of the average number.

SAMPLE M

Twofold 40's, 12·2 turns, spun from Leicester Botany Wool.

Number of Experiments.	Twist taken 5 Inches together.	Average Twist per Inch.	Twist taken Inch by Inch.	Average Twist per Inch.
No. 1	60 50 63 55 58	11·44	11 12 9 14 11	11·40
No. 2	66 63 52 48 56	11·40	13 13 10 11 8	11·00
No. 3	69 55 56 50 58	11·52	12 7 14 14 10	11·10
No. 4	70 72 66 54 55	12·68	13 13 8 13 9	11·20
		11·76		11·25

The greatest variation in the number of turns taken 5 inches together is in No. 3, from 50 to 69 turns = 19 turns, or 32 per cent of the average number of turns. The greatest variation when taken inch by inch is in No. 3 thread, from 7 to 14 turns = 7 turns, or 62 per cent of the average number.

SAMPLE N

Twofold 50's, 15·3 turns, spun from Leicester Botany Wool.

Number of Experiments.	Twist taken 5 Inches together.	Average Twist per Inch.	Twist taken Inch by Inch.	Average Twist per Inch.
No. 1	66		14	
	72		16	
	70		12	
	68		18	
	74	14·00	10	14·00
No. 2	77		20	
	75		13	
	60		17	
	78		16	
	74	14·56	12	15·60
No. 3	55		11	
	75		18	
	75		20	
	78		10	
	68	14·04	21	16·00
No. 4	80		13	
	82		16	
	74		15	
	70		11	
	69	15·00	17	14·40
		14·40		15·00

The greatest variation in twist taken 5 inches together is in No. 3 thread, from 55 to 78 turns = 23 turns, or 32 per cent of the average number. The greatest variation when taken inch by inch occurs in No. 3 thread, from 10 to 21 turns = 11 turns, or 73 per cent of the average number.

SAMPLE O

Twofold 60's, 19·6 turns, spun from Botany Merino Wool.

Number of Experiments.	Twist taken 5 Inches together.	Average Twist per Inch.	Twist taken Inch by Inch.	Average Twist per Inch.
No. 1	75		19	
	90		10	
	100		17	
	98		20	
	102	18·60	16	16·40
No. 2	80		24	
	95		21	
	100		13	
	100		17	
	96	18·84	11	17·20
No. 3	102		25	
	94		28	
	105		18	
	88		18	
	100	19·56	14	20·60
No. 4	104		15	
	100		21	
	89		28	
	88		28	
	95	19·04	20	23·00
		19·01		19·30

The greatest variation in number of turns when taken 5 inches together is in No. 1 thread, from 75 to 102 turns = 27 turns, or 28 per cent of the average number. The greatest variation when taken inch by inch is in No. 3, from 14 to 28 turns = 14 turns, or 72 per cent of the average number.

SAMPLE P

Twofold 70's, 23·3 turns, spun from Botany Merino Wool.

Number of Experiments.	Twist taken 5 Inches together.	Average Twist per Inch.	Twist taken Inch by Inch.	Average Twist per Inch.
No. 1	101		20	
	100		24	
	123		14	
	103		20	
	120	22·00	18	19·20
No. 2	125		21	
	100		27	
	114		21	
	118		22	
	128	23·40	13	21·40
No. 3	130		10	
	128		30	
	117		25	
	111		24	
	122	24·32	20	21·80
No. 4	103		13	
	118		25	
	100		26	
	99		28	
	101	20·84	17	21·05
		22·64		21·55

The greatest variation in twist when taken 5 inches together is in No. 2 thread, from 100 to 128 turns = 28 turns, or 25 per cent of the average number. The greatest variation when taken inch by inch is in No. 3 thread, from 10 to 30 turns = 20 turns, or 95 per cent of the average.

SAMPLE Q

Twofold 80's, 28·8 turns, spun from Botany Merino Wool.

Number of Experiments.	Twist taken 5 Inches together.	Average Twist per Inch.	Twist taken Inch by Inch.	Average Twist per Inch.
No. 1	160		20	
	130		32	
	148		29	
	128		35	
	140	28·24	24	28·00
No. 2	150		25	
	166		22	
	170		29	
	122		33	
	135	29·72	26	27·00
No. 3	158		34	
	166		26	
	162		38	
	130		30	
	124	29·72	25	30·60
No. 4	147		27	
	125		22	
	135		34	
	158		35	
	130	27·80	22	28·00
		28·84		28·40

The greatest variation in twist when taken 5 inches together occurs in No. 2 thread, from 122 to 170 turns = 48 turns, or 33 per cent of the average number. When taken inch by inch the greatest variation is in No. 1 thread, from 20 to 35 turns = 15 turns, or 53 per cent of the average number.

In looking at the general results of these experiments we are struck with the great irregularity in twist, even when the tests are made in 5 inches, since they vary from 23 per cent in sample L to 40 per cent in sample J, the average variation in all the samples taken together being 30 per cent of the average twist per inch. This is considerably greater than in cotton yarns, where in similar counts of twofold yarns the average variation is only about 18½ per cent, with an extreme variation of from 11 to 26 per cent. When we come to the tests taken inch by inch in these worsted samples, we find the variation far greater—so great, indeed, as to excite our utmost astonishment, and especially when we recollect that all these yarns are by first-class spinners and high-class yarns. The extreme variation is from 53 per cent in sample Q to 95 per cent in sample P, and the average of all the tests gives 69·4 per cent. At the head of each test I have given the number of turns of twist which was aimed at by the spinners, and it will be noticed that in every case except the last the theoretical twist is in excess of the actual, showing the loss from the slip of the band on the wharf of the spindle. In the case of cotton yarns, the average variation in twist, when taken inch by inch, is about 38 per cent, which is only rather more than half that in worsted, and the extreme variation from 23 to 50 per cent. Any irregularity in the single yarn seriously affects the twist in twofold, because the thick place presenting great resistance to torsion throws the twist into the thinner part of the thread, and we may readily learn from this that it requires good single yarn to make good twofold. All the experiments—and those given in the foregoing pages are only samples of a considerably larger number taken both from fly, cap, and ring spinning and doubling—go to show

that by far the greatest cause of variation, both in strength and twist, arises from the variation in the raw material itself. The greatest care should be exercised in the sorting of the wool if first-class results are to be obtained, so as to secure uniformity in the quality of the fibres to be used, because there is a singular tendency in worsted spinning for the thick fibres to associate with thick ones, and fine ones with fine, and the presence of these in the thread increases the difficulty of regularity in drawing and regularity in the putting in of the twist, or, at any rate, in the capacity of the thread to retain the twist in a regular manner, even if put in by perfect machinery. The law of averages gives wonderful results when taken over a series, but at present the author is of opinion that the perfection in spinning is in excess of the perfection in preparing the fibres for spinning, and decidedly in advance of the present state of perfection in the raw material which we have to use. This opens a wide field for further scientific sheep culture.

CHAPTER XIV

THEORY OF DYEING AND COLOUR

So far the structure of the wool fibre has been considered both mechanically and chemically, without any direct regard to its relation to colouring matter. The wool fibre is built up of a series of cells, which are arranged so as to secure lightness and strength, and enclosed within an epidermal sheath of similarly constituted cells, which are flattened out into more or less horny scales, arranged on the surface of the fibre in such a manner as to allow of the most perfect freedom of flexure in the fibre itself, while they present a series of reflecting surfaces which in the lustre wools attain an almost metallic brightness. The chemical composition of wool is the same as that of the horny tissues generally, and consists of a series of more or less distinct albuminoid bodies, the whole of which are considered by some chemists to be represented by a definite chemical compound, Keratin, having the formula $C_{42}H_{157}N_5SO_{15}$. It has been seen that a great variation exists in the mechanical structure of fibres, not only taken from different races of sheep and different flocks, but also from different parts of the same sheep; also how these mechanical differences in the structure and magnitude of the wool fibre affect its use in the manufacture of yarn and goods, and also the irregularities which these variations

have introduced into the different classes of yarn. It is now necessary to go a step farther and inquire how far these differences, when taken along with the chemical composition of the wool, affect its use in the manufacturing process.

II. *Chemically.*

It must be remembered that there is a distinct difference between the relation which the chemical structure of the fibre bears to its mechanical structure, and that which both these qualities taken together bear to the external chemical treatment to which it may be subjected in the process of manufacture. While the ultimate analyses of different wool fibres seem to indicate that there are variations in the chemical composition which are co-extensive with mechanical variations, they do not indicate the exact position in the structure where these variations occur in the same way that the microscope reveals mechanical differences.

Cell-Contents.—Along with the matter which actually forms the structural part of the wool—that is, the various cell-walls and their enclosing membranes—there are always a number of cell-contents, lubricating oils and fats, and mineral constituents, including endochrome, which, while they are not the wool itself, are so associated that they must be considered along with it; and as they vary from time to time, and in different wools, will also vary the reaction which the fibres will have with chemical reagents, whether the latter are dyeing materials or not.

In the manufacture of textile fabrics, except in the case of the very coarsest materials, the element of colour and the process of dyeing play a very important part, and no consideration of the technical relations of the wool fibre would be complete without some consideration of that which it bears to the various colouring matters and dye-stuffs to which it has to be subjected.

Just as there has been no attempt in any way to deal with the mechanical processes which are necessary in spinning and weaving the wool fibre, so the work will not describe the actual process of dyeing; but look at the effect which is produced when the process is finished, and endeavour to ascertain what has been the actual change which has been produced, and the mechanical as well as the chemical manner in which the colouring matter and fibre are united.

Inertness of Cotton.—When looking at the relation of the cotton fibre to colouring matter, and indeed to all chemical changes, it was seen that cellulose was remarkably inert, so much so that its properties were almost best defined as a series of negative results. The exact composition of cellulose, of which there are many varieties, is not yet determined, and the term must therefore be taken to represent a group of closely allied bodies rather than a single chemical compound. Generally it may be defined as a saccharacolloidal carbohydrate having the general composition $N(C_6H_{10}O_5)$, of which the typical constitutional unit or C_6 group may be formulated as

$$\begin{array}{c} O \\ CH\,.\,CHOH\,.\,CH\,.\,CHOH\,.\,CHOH\,.\,CH_2 \\ O \end{array}$$

an expression which fairly generalises its reactions.[1]

In the cotton fibre, which is never entirely pure cellulose,

[1] Thorpe's *Dictionary of Applied Chemistry*, p. 455, Longmans, London, 1905.

and always contains some unchanged protoplasm, which is always the same either in plants or animals, reactions may occur as a result of these and the mineral constituents, which, unless carefully differentiated, might be attributed to the cellulose group. When the cellulose is pure, its action with chemical reagents, with the exception of very strong acids and alkalies, is almost *nil*, and when it is necessary to produce permanent colours upon it, or better still within it, this can only be accomplished by a series of secondary reactions in which the cellulose plays so unimportant a chemical part, that many chemists are of opinion that its action is as strictly mechanical as if the cotton fibre was a glass tube. This theory, which was strongly advocated by Mr. W. Crum, F.R.S., regards the colouring matters produced on cotton as simply an entanglement of the colouring matter within the successive envelope walls of the cotton fibre, in which the latter only serves the part of a containing vessel by holding the colouring matter within it. The author differs from this theory, as there are reasons for believing that, while this is true in regard to some classes of colouring matter, it is certainly not so in regard to others. It has been pointed out that, while pure cellulose is one of the most inert of bodies, it is never found in a perfectly pure state in the cottons of commerce, but always associated with oils, oily waxes, and unchanged cell-contents, and with more or less mineral constituents in the form of metallic salts, which have an affinity for other chemical reagents and a distinct reaction with them. Recent researches have only confirmed this opinion, while those of Prof. Witz in France, and Messrs. Cross and Bevan[1] in this country, have shown how the cellulose molecule may be modified by oxidation

[1] *Journal Society of Chemical Industry*, No. 4, vol. iii. p. 206.

and rendered capable of an affinity for various colouring matters which it did not possess before.

Activity of Wool.—Animal fibres differ entirely from vegetable fibres in their chemical character, as not only in the former is the molecule very much more complicated, but it possesses direct affinities for various other bodies, both coloured and colourless. It is only to be expected that with a more complicated molecule, the greater will be its range of affinities, because it offers, from its greater atomic heterogeneity, more points of attack in the presence of other substances, and so many more links in the atomic chain where attachments may be formed. Even this, however, does not explain the much greater readiness with which animal fibres unite with colouring matter; and there seems to be, from the very mechanical structure of the fibres, a greater adaptability to receive and retain the dyes which render wool better fitted than cotton for the reception of colour, for, after all, the power to reflect colour is dependent upon a mechanical arrangement of the molecular surface of the coloured body. This structure is too minute to examine even with the best microscopical power at command, but just as the molecular structure determines the nature of the system of rays which can be reflected from it, so the nature of the rays reflected enables us to gain some little insight into the nature of the surface from which they emanated, and whether that surface is uniform in its structure or not.

Cause of Colour.—Strange as it may appear, there is really no such thing as colour as an attribute of any substance. The sense of colour is entirely derived from the nature of the undulations of the all-pervading luminiferous ether which are returned from the surface of the body to the eye, and it is there alone that the colour

sense is manifest. It has merely a subjective existence, and is due to the triple constitution of nerves within the retina. Outside the eye the whole universe is dark, and what produces the sense of colour is only an undulation in the ether, in which the length of the undulating wave determines the specific character of the colours, and the amplitude of the wave the intensity. Undulations in the same ether, which give no sensation of light when falling upon the eye, are thrown off from the surface of the body along with the luminous undulations, and all these are so mingled together that they shade into each other, and some eyes which possess a greater range of sensibility can see the form of bodies which are almost invisible to others. When the eyes fail there is the discerning power of chemically prepared surfaces, which far exceed in range the nervous surface of the retina, and the faint impressions which are fixed can be chemically built up till they will throw off undulations discernible by the eyes, so that now it is possible to photograph appearances invisible to the ordinary senses. The author has taken photographs of objects in total darkness to the eye. The longer and slower undulations—that is to say, slower in the sense of a fewer number occurring in a second of time—give only the impression of a faint dull red, and as they increase in number the colour changes through brighter red to orange, yellow, green, blue, indigo, and finally violet, which in its most attenuated form marks the extreme limit of the sensibility of the eye to the most rapidly undulating waves. While speaking of slow and rapidly undulating waves in the ethereal medium, it must be remembered that these terms are only relative. The slowest wave which will affect the eye undulates 392,000,000,000,000 times in a single second, and this gives the sensation of the faintest

red, while the frequency of the extreme violet undulations at the other end of the range of sensibility is 757,000,000,000,000 per second. The mean length of these undulations is only about $\frac{1}{48000}$ of an inch.

Between these limits there is an indefinite variety of integral and fractional numbers, each of which represents the frequency of a particular kind of radiation—a particular kind or colour of light—so that there are as many kinds of colour possible as there are possible kinds of radiation between these limits, and in all sober truth, therefore, the number of actual colours is almost infinite. From physical causes connected with the nature of the atmosphere of the sun and earth, many of these intermediate radiations are extinguished, and hence there are many colours which cannot be seen by daylight, and which are present in the light coming from other incandescent bodies, such as the oxyhydrogen, limelight, or the electric arc, and hence the peculiar effect produced on the eye when coloured bodies are seen with these lights. If the light under which a body is seen only possesses in it one set of undulating rays, or is a one-coloured light—monochromatic, as it is termed —then all bodies, however varied in colour when seen in ordinary daylight, cease to have any distinction except being darker or lighter varieties of the same shade. Take a box of coloured silk ribbons, the more varied in colour under ordinary conditions the better, or a set of samples of highly-coloured wall-papers, or a dyer's most varied shade card, and illuminate them solely with the light of an alcohol flame in which common salt has been dissolved, and, though the form of the objects remains, the colour is all gone except a sort of yellowish grey. It is impossible to tell red from blue, or yellow from green. All colours except black and white seem very similar, and a painting

or coloured design looks like an Indian-ink sketch on a yellowish paper. The appearance of colour on all bodies depends upon two circumstances and not one. It depends upon the nature of the surface of the body in regard to its molecular structure being such that when white light, which is really a mixture of all wave-lengths, falls upon it, it shall suppress all undulations but those of one definite wave-length, and return these alone to the eye, and then there is a pure monochromatic colour. But it also depends upon the nature of the light which falls upon the reflecting surface, because if rays of the wave-lengths which it is best fitted to return to the eye are absent, or few in number, the colour will be dim and unsatisfactory. Hence many fabrics which when dyed look beautiful in daylight are anything but beautiful in gaslight. If it is wished to see perfectly pure monochromatic colours, it is necessary to look at the band of light which is produced by passing the rays from an electric light through a prism. In passing through the prism the rays are bent or refracted, and this refraction sorts the rays out into their wave-lengths in a definite order, producing the brilliant-coloured band known as the "spectrum."

Composition of Colour.—We have already named these primary colours in their order, from the red to the violet, but between each definite colour the eye detects, at any rate in the brightest part of the spectrum, something like transitional colours—half shades intermediate between those which are perfectly definite and distinct. They may be classed as follows:—

ANALYSIS OF THE SPECTRUM

Definite Shades.	Half Shades.
Red.	
....	Orange-red.
....	Reddish orange.
Orange.	
....	Orange-yellow.
....	Yellowish orange.
Yellow.	
....	Greenish yellow.
....	Yellowish green.
Green.	
....	Bluish green.
....	Greenish blue.
Blue.	
....	Ultramarine.
Indigo.	
....	Blue-violet.
Violet.	

If all except a single part of the spectrum is cut off, these half shades become less distinct to the eye, because in the continuous spectrum they are intensified by the proximity of the two distinct colours on each side of them, but they are still visible, and the narrower the part of the spectrum which is observed the more distinctive the colour, which shows that although intermediate they are monochromatic. These intermediate colours may be got in another way. The eye is not a perfect instrument, and indeed if it were more sensitive and discriminating it would serve its ordinary purpose less efficiently, and so it is possible to produce, by the action of a series of independent wave-systems upon the retina, effects which, although they differ in the method in which they are produced, are identical in the results so far as the sense of vision is concerned. For example, take a piece of

greenish-blue glass, and the light transmitted through it will appear to the eye identical with the monochromatic light of the rays which form the half shade between the green and blue, and nearest to the latter; but if analysed through a prism, it is seen that the cause of the sensation is entirely different. The half shade of the same tint was in the spectrum purely monochromatic, and if again sent through a prism would be equally refracted; but the same apparent colour from the coloured glass, when analysed with a prism, is formed into a short and imperfect spectrum, consisting of green, blue, and yellow light, with perhaps several other colours more or less faintly represented, and sometimes with considerable gaps between the colours, showing that they are produced by distinctive wave-systems. Many of the best dyed colours are of this character. They appear to the eye monochromatic, but are really not so. The dyed surface is not, therefore, homogeneous, but the molecules are arranged so that they throw off several systems of rays whose total effect has the same result on the sense nerves as if they were monochromatic; and since it is found that many such mixtures may produce the same apparently simple sensation, it shows that there is a considerable latitude allowed in the molecular structure of the reflecting surfaces without injuring the results. If it were not for this, the processes of dyeing would be still more difficult than they are, and far more uncertain.

When pursuing these investigations, the author examined the surfaces of a large number of dyed fabrics with a powerful direct-vision spectroscope, and found that a number of colours which appeared almost similar to the eye differed very considerably in the nature of the spectrum which the reflected light yielded. As an example of these,

a range of aniline shades dyed upon camlets may be taken, which gave the following results:—

Colour to the Eye.	Nature of Spectrum.
1. Light slate colour...	More or less continuous spectrum, with bands of red, blue, and green.
2. Dark slate...........	Similar spectrum, but with extension of green into blue.
3. Bright orange........	Short red spectrum, with extension into the yellow and green.
4. Scarlet..............	Bright continuous red and yellow spectrum, with slight extension into the green.
5. Emerald green......	Continuous yellow, green, and blue spectrum about equal.
6. Sage green...........	Red, yellow, and green spectrum, the yellow being the longest.
7. Light blue..........	Short spectrum, yellow and green, with short extension into the blue.
8. Dark blue...........	Short blue spectrum, with extension into the green and yellow.
9. Violet...............	Short red spectrum, with yellow omitted but extending into green and blue.

In making these observations great care requires to be taken to exclude all light except that which is directly returned from the surface of the fabric, because at many angles with the spectroscope there is a certain amount of white light reflected from the surface of the fabrics, and this masks the true reflection from the dyed fibres, and gives a more or less continuous spectrum, in which all the colours are represented. The author found, also, that two colours on similar fabrics which to the eye appeared almost identical gave a different spectrum when examined with the spectroscope. Thus, two pieces of similar cotton, one of which was dyed turkey red and the other an aniline red, but which were not distinguishable by the eye, were

quite distinct in the spectrum. The turkey red gave a much shorter and more distinct red spectrum, which in the case of the aniline was extended much further into the yellow and green.

Analysis of Colour.—The author was particularly struck with the fact that as a rule the aniline colours give a longer and more continuous spectrum than those derived from other sources. Thus, the spectrum reflected from the surface of an aniline blue of the same shade as another cloth dyed with indigo seems to be of a greater length. This may, perhaps, account for the greater brightness and brilliancy of the aniline colours, since the retina of the eye is affected by a wider range of vibrations, and in that respect the action is a nearer approach to that of white light. The difference is the same as between a solo and a chorus in music—the solo corresponding to the monochromatic spectrum, and the chorus to the effect produced by the system of different degrees of refrangibility. Those who are acquainted with recent chemical researches know that the examination of absorption spectra of saline and organic liquids, first by Gladstone, and afterwards by Bunsen and Russell, as well as by Hartley for the ultra-violet and Abney and Festing for the infra-red region, have led to interesting results in regard to molecular chemistry. Hartley found that in some of the aromatic compounds definite absorption bands in the more refrangible region are only produced by substances in which three pairs of carbon atoms are doubly linked, as in the benzene group; while Abney and Festing found that the radical of an organic body is always represented by certain well-marked absorption bands, differing, however, in position according as it is linked with hydrogen, a halogen, or with carbon, oxygen, or nitrogen. Indeed, it is not improbable

that by this method of examination the hypothetical position of any hydrogen, which is replaced, may be identified, and this result has been rendered all the more probable by the recent researches of Perkin on the connection between the constitution and optical properties of chemical compounds.

An equally interesting field of observation is opened up by the examination with the spectroscope of the various dyes when in a state of solution, when we have a wonderful series of differences in the absorption bands, a study which some day may throw much light on the character of the molecular structure of the colouring matters themselves. In this case, the rays which are transmitted through the dyes are examined, instead of those reflected from the surface.

The best method of producing these artificial colours upon different textile materials constitutes the art or science of dyeing, and the most remarkable fact, upon which the process of dyeing depends, is the degree of facility with which various fibres, and especially those of animal origin, receive and retain the various colouring matters. From what has been seen regarding the nature of light, it follows that all dyeing processes are simply the production of such a molecular condition on or within the surface of the fibres, that they will return certain luminous wave-lengths to the eye and suppress or destroy others, till we have the effect so beautifully described in one of Tennyson's "Idylls of the King," in which the mother of Enid brought

> "A suit of bright apparel, which she laid
> Flat on the couch, and spoke exultingly—
> 'See here, my child, how fresh the colours look,—
> How fast they hold,—like colours of a shell
> That keeps the wear and polish of the wave.'"

Perfect dyeing must have these two attributes: *clearness of colour*, like the colour produced by diffraction from thin transparent films or closely-ruled lines, as in a diffraction grating; and *permanence*, so that the colours will remain fixed under all the conditions to which the fabrics are likely to be exposed in the uses to which they will be put.

Theory of Dyeing.—The *rationale* or theory why and how this desired reflecting surface is obtained by what we term the fixation of various colours upon fibres or fabrics, is a matter of dispute and doubt even to the greatest authorities on these questions; and there is evidently a different solution to be given to the problems in the case of animal fibres, such as wool or silk, as compared with cotton or any vegetable fibre. This has been more fully treated in the work on the structure of the cotton fibre, to which the reader is referred.[1] There are really three theories which have been put forward.

(1) **The Chemical Theory.**—That the fixation of the colouring matter, however produced, is accomplished by an affinity or attraction between the colouring matter and the fibres in the same manner, but differing in degree from the ordinary chemical combination which occurs between unlike chemical bodies in which colour is produced.

(2) **The Physico-Chemical Theory.**—That the fixation of colour does not depend entirely upon any chemical affinity which may pertain between the fibres and the colouring matter, but also upon the mechanical structure of the fibres or fabric, which by absorption within the structure of these, fixes the colour and forms a reflecting surface, the fixity depending on the nature of the colouring

[1] Bowman, *Structure of the Cotton Fibre*, p. 387, Macmillan & Co., Ltd., London, 1908.

matters themselves as well as on the degree of mechanical stability within the structure.

(3) **The Mechanical Theory.**—That there is no chemical relation or reaction between the fibres or fabrics and the colouring matter, but that the layers or walls of the fibres simply form so many successive envelopes within which coloured pigments are deposited, and that the colour is entirely dependent upon the nature of these pigments themselves, which form the reflecting surface, and the permanency upon the degree of mechanical shielding which the structure of the fibre or fabric yields to the pigment.

Another theory—the Solution Theory—has been proposed by Dr. Otto Witt as an explanation of the dyeing of direct cotton colours, but he also applies it to all substantive dye-stuffs. This theory assumes that any fibres dyed with a purely substantive colour are a solid solution of the dye-stuff. The great difficulty, however, is the fact that an alteration in the chemical composition of a fibre usually influences its affinity for dyes, and thus supplies evidence in favour of the chemical theory.

The author's opinion is decidedly in favour of the second of these theories, and he would give it the very widest interpretation, so that in its two extremes there may be on the one hand cases where the affinity between the colouring matter and the fibres exercises a most important part both in the production and fixation of the colour; while on the other hand there are a large series of cases where, from the nature of the colouring matter employed, they must exercise far more of the character of simple pigments, in which the affinities of the fibre are subordinated to their mechanical structure.

Modern research is indeed continually narrowing the

dividing line between all the different branches into which scientific knowledge has hitherto been classed, and to consider all changes which matter undergoes, and the means by which these changes are effected, as purely physical, and that both are subject to the same laws of mass and dynamics, modified only by the distances at which they act, the nature of the conditions, and stability of their motions. These laws must necessarily be varied, when it is remembered that in the great majority of cases both the substance to be dyed and the dyeing materials are put under conditions in regard to temperature and moisture, as well as one of them being in solution, which are eminently favourable to determine change in each, and that care has always to be taken to prevent the physical properties of the material to be dyed, such as strength and flexibility and lustre, being in any way altered, and therefore that this mechanical texture must act both in regard to capillary action and molecular entanglement upon the dyeing solution, exactly the same as if it was only a fluid possessing the same physical properties. This theory is probably the one which is now the most universally accepted, and which may be said in most cases to give the most rational explanation of the phenomena, and will account for the action of both simple and complex dyes.

It must not, of course, be understood that in any case the reaction between the fibre and that of the colouring matter, even when speaking of their having a chemical affinity, is of the same order and degree as that between oxygen and potassium. The whole reaction is much feebler, and chemists have not yet been able to detect, except in a few cases, any exact and definite proportions in which the combination takes place, and, until this is proved, it can scarcely be said that the

dyeing of fibres is in any case a strictly chemical operation, and yet in the case both of wool and silk it is not certainly strictly mechanical. Speaking on this point M. Schützenberger, in his work on dyeing, says: "The cause of the absorption of colouring matter by wool does not reside simply, as might be thought, in the porous structure of the fibre, analogous to that of animal charcoal, for all the nitrogenised substances of the class of albuminoid protein compounds show the same character in a greater or less degree. Coagulated albumin, for example, approaches remarkably near to wool in respect of its powers of dyeing. It has been sought to explain the attraction which silk and wool have for soluble colours by supposing that these substances contain a peculiar organic mordant. Evidently it is the fibre itself which plays the part of a mordant. It combines chemically with the colour, since it causes it to lose one of its characters, its solubility. From this combination a true lake results, differing from the ordinary lakes in so far as the metallic oxide is replaced by an organic substance."[1] The question of the lakes is a difficult one, because it is by no means yet certain that any of the lakes even which have a metallic oxide for their bases are themselves true chemical compounds, especially the lakes which are of most importance, such as those formed with alumina, iron, and tin.

While the whole question is still involved in considerable doubt, so far as actual proof is concerned, there can be no question that in many cases there are instances of undoubted chemical combination, and it must always be remembered that all wool fibres have always associated with them, as an integral part of their structure, a certain amount of metallic salts in the form of inorganic constituents, and

[1] *Traité de Matières Colorantes*, vol. i. p. 192.

even very small quantities of these diffused through the cell-walls may act the part of mordants to the colouring matter, so as to fix and render them insoluble. Those who object to this theory, on the ground that these metallic salts are so small in quantity, must remember the exquisite sensibility of many of the colour tests of the various metals, such as iron with potassic ferrocyanide, where the blue colour is produced and visible to the eye, even when the dilution is enormously great. We may therefore expect to find both chemical and mechanical reactions.

Chevreul's Theories.—This is really the theory of dyeing which was advanced by M. Chevreul, who believes that the matter which colours fibre is fixed in the fibre in three different ways:—

(1) By chemical affinity.

(2) By simple mixture with the fibres.

(3) By being in both states at once.

By the latter statement he means not that the same matter is in both states at once, but that the colour of the fibre is due partly to the union of the fibre with the colour chemically, and partly to the presence of the same colouring matter in a state of mechanical mixture with the material forming the fibre cells.

Probably, indeed, no general theory of dyeing can be formed which will include all cases and all classes of fibre until there is a much wider knowledge, based upon careful experimental research in many individual cases, and which alone can form the basis for any extended generalisation.

It must be also remembered that in every dyeing process the results are dependent upon two functions and not one,—there is the fibre to be dyed, but there is also the dye to dye it, and the nature and action of this dyeing

material, whether it is derived from mineral, vegetable, or animal sources, or produced artificially, cannot be left out of account when studying the phenomena. As these dye-stuffs differ in their origin they also differ in their character, and their classification may be based therefore upon various methods, depending upon the standpoint from which they are viewed, as, for instance, their origin, in which case they may be divided into two principal groups:—

1. **Natural dyes**, which are mostly the products of organic life, such as coloured vegetable infusions and extracts. These do not, however, usually exist in the plants as coloured bodies, but as potential colouring matter, or chromogens, as they have been termed, because they must undergo a process of fermentation and oxidation in order to become coloured, as in the notable case of indigo.

2. **Artificial dyes**, which are the products of chemical synthesis, such as most of the coal-tar products, and which, as the science of organic chemistry becomes more fully known, seem destined to supersede all the others, as in the case of artificial indigo and alizarine, which have substantially replaced natural indigo and madder.

Viewed in relation to their action, Bancroft, in his *Treatise on Permanent Colour*, written at the beginning of the last century, divided them also into two classes.

1. **Substantive dyes**, or those dyes which will dye the fibre directly and without the intervention of any mordant or fixing agent, such as indigo extract, chrysophenin, or benzopurpurin.

2. **Adjective dyes**, which will only dye the fibres when they are treated or mordanted with a metallic salt or oxide, which, when added to the dyeing bath or where the fibres have been previously treated with it, fix the colour upon and within the fibres in a permanent form. For example,

logwood, alizarine, cochineal, and fustic, which when used along with iron, alumina, chromium, tin, etc., produce intensely coloured lakes within the substance of the fibres that are quite fixed and permanent.

In some cases the dye-stuff only yields one class of colour, whatever mordant may be used, whereas others yield a series of colours where different mordants are employed. The former class, amongst which may be named magenta, orchil, indigo, etc., have been termed mono- or autogenetic dyes; while the latter, which are mostly adjective dyes, like those named above, have been termed polygenetic. This is the classification adopted by Hummel in his work on the *Dyeing of Textile Fabrics* (p. 147).

A third method of classification may also be adopted which is neither based upon the origin nor constitution of the dyeing materials, but upon their method of action—that is to say, the means or method which has to be employed to bring them into union with the fibres.

1. Acid dyes.
2. Basic or tannin dyes.
3. Substantive or direct cotton dyes.
4. Mordant dyes.
5. Vat dyes.
6. Dyes formed or developed on the fibre.
7. Sulphide dyes.

It has already been seen that so far as cotton is concerned its relation to any dye-stuffs is much more passive than that of either wool or silk, and that most of the dyeing operations are conducted in a neutral or alkaline and not an acid bath. In their relation to cotton, dyes may be said to be of three kinds:—

1. Those which are coloured in themselves, and which may be termed simple dyes, having a direct affinity for

the fibre without the intervention of a mordant, such as turmeric yellow, and the whole series of artificial direct dyes, such as Congo, benzadine, diamine, etc., dyes.

2. Those which are true chemical precipitates formed within the walls of the fibre, in which the action of the fibre seems to be purely mechanical, of which such colours as Prussian blue, indigo blue, etc., and chrome yellow are examples.

3. Those where a mordant is necessary, and the colour is not produced by the simple union of the fibre with the colouring matter, nor by the formation of lakes within the meshes of the fibre, but by the union of the mordant with the fibre and the reaction of the mordanted fibre and the dyeing material, of which the most important are Turkey red, several catechu dyes, and in a secondary degree logwood black and all the tannin dyes.

A similar subdivision of the colouring matters obtains in the case of wool, the acid colours being the most important examples of class 1, indigo being the representative of class 2, and the alizarine colours, of which there is now a very extensive variety, are representatives of the third class.

A class of colours is also now largely used which seem to illustrate, in the method of application to the wool fibre, a combination of the reactions of classes 1 and 3. These are known as the After-chrome colours. There are also the Meta-chrome colours, in which mordants and dye-stuff are applied in one operation.

Although these threefold methods of action of the dye-stuffs in relation to the materials to be dyed seem to indicate considerable differences in the method of operation, still, a careful examination of the nature of the classified dye-stuffs seems to indicate that the mutual relations of the

members of each class, in regard to the fibres and to themselves, depend more upon a single property held by them in common than upon their actual composition. This appears to be their acid or basic qualities, or, in cases where both, as resulting from the composition of the dye-stuff, are present, upon the relative balance of the two.

General Relation of Dyeing Materials.—Thus all the acid dyes, whatever may be the specific character of their acid properties, and from whatever acid derived, behave in regard to the fibres to which they are applied in a similar manner, because the acid property is generally due to the presence of sulpho, nitro, and hydroxyl groups in their composition, of which the last are usually the most active, and their action seems to indicate only differences in degree and not in kind.

In the same way all basic dye-stuffs, whether azo compounds such as chrysoidine, or triphenylmethane derivatives such as magenta, as a consequence of one or more amido groups which are present in each, and upon which their basic action depends, exhibit more or less the same pigmentary character.

All the substantive dyes indeed, in this relation, contain more or less basic and acid groups in their composition, and are thus able to react without the aid of a mordant upon any fibre or other material which contains in itself either of these properties; and in their relation to the dyeing of cotton it is quite clear that it is the basic constituents in the dyes which react with the hydroxyl groups in the cellulose. With regard to cotton dyeing the same remark also applies to adjective or mordant dyes, in which the reaction evidently not only depends upon the acid character of the hydroxyl groups, but also upon the nature and arrangement of the groups themselves within

the cellulose molecule. If this was not the case, the capacity of a dye for fixing with mordants would be increased and not diminished by the presence of strongly acid sulpho groups.

With these general remarks it is now possible to consider the general principles of the relation between the dyeing process and the mechanical structure of the fibres to be dyed.

Process of Dyeing.—Whatever the nature of the fabric to be dyed, or of the dye-stuff to be used, the universal practice is to present the dyeing materials to the fibre or fabric dissolved in water or other menstruum, either cold or hot. The dyeing process arises from the absorption of the dyeing material in solution into the substance of the fibre.

From whatever cause this action arises, the absorption always proceeds in one manner, viz. the dye is absorbed more rapidly at first, and gradually diminishes until a point is reached where no more will be withdrawn from the solution, however long the material to be dyed is retained in the bath. This action may be represented graphically by means of a curve drawn upon a chart, in which one dimension represents time, and the other the quantity or percentage of material withdrawn from the solution. This curve differs for every material, and generally for every class of dye-stuff. In most cases the absorbent action is increased by raising the temperature of the dye-bath up to the boiling point. There are cases in which, if the quantity of dye is small in proportion to the quantity of material to be dyed, the whole of the colouring matter will be extracted from the solution. As a rule, however, a portion of the dye always remains in the bath.

There is a point, however, reached, in the case of all fibres, in which a maximum of effect is attained, and beyond which no further absorption takes place; and it must be specially noted that the first portions of the dye, which are absorbed the most rapidly, are always the most permanent and fixed, on and within the fibres, which seems to indicate that in some way the power to absorb decreases the longer it is exercised, as if either the affinities become saturated or some other mechanical change occurs which hinders the absorption by filling up the pores. It is found also that all fibres absorb relatively more dye in proportion from dilute than concentrated solutions, and that under these circumstances the attachment of the dye to the fibre is more fixed. Whenever dye-stuff has been absorbed by a fibre it can never be again entirely removed by washing with cold or hot water, even if the dye is completely soluble in water, which shows that the dye, although it has undergone no change in chemical composition, has in some manner changed in regard to the solvent by its absorption into the texture of the fibre. That the characteristics of the dye within the fibre are unchanged can be proved by the reaction being with other bodies exactly the same as possessed by the dye-stuff itself with the same bodies outside the fibre. Thus dyes containing a free amido group can be diazotised on and within the fibre, and converted into more complex azo dyes by coupling with phenols and amines; and very dark dyeings with magenta, methyl violet, and similar dyes will bronze exactly the same as outside the fibre. The dyed fibre behaves in all respects like a salt of the dye-stuff.

It has also been found that where more than one dyeing material is used in treating a fibre or fabric the absorption exercised in the case of one is quite independent

of the others, or of the order in which they may be made to come into action, so that since their action is quite separate it is immaterial whether they are made to act successively or at one and the same time. Care must also be taken that they are not of such a character that they react with each other, and so either form a new combination, which is soluble in the solution, in which case the new substance would act independently, or cause a precipitate, when they would be removed out of the solution and so entirely cease to act. There may, it is true, be a difference in the time element between them, but in any case it is necessary that the material to be dyed shall remain in the solution sufficiently long to enable equilibrium to be established in regard to the distribution of the dye between the fibre and the dyeing solution.

Georgievics (*Chemical Technology*, 1902, p. 132) suggests that this relation between the definite absorption of the fibre and the quantity of dye absorbed in relation to the quantity remaining in the dye-bath, after the saturation of the fibre by the dye is complete, points to a general law, according to which our dyeing processes should be conducted.

Law of Distribution.—In regard to this he remarks as follows:—

"This behaviour of dye-stuffs in dyeing must be based on some definite law, which may be ascertained by the quantitative examination of the distribution of a dye between the fibre and the bath.

"By determining how much dye has been taken up by the fibre, and how much is left in the bath, and calculating, from these data, what quantities of dye are contained in equal weights of the fibre and the bath liquor, we obtain two values which may be expressed as Cf (fibres) and Cb

(bath). The quotient $Cf \div Cb$ is termed the coefficient of distribution, and its dimensions depend on the nature of the dye-stuff and fibre, the temperature of the dyeing process, and the concentration of the bath liquor in relation to the amount of fibre treated. The rule is, that the coefficient of distribution slowly sinks as the concentration of the bath increases. If this diminution of the coefficient be actually quite uniform, then, for mathematical reasons, the expression $\sqrt[x]{\frac{Cb}{Cf}}$ must possess a constant value independent of the concentration. This is, in fact, actually the case in two instances, viz. the dyeing of silk with indigo carmine at boiling heat, and the dyeing of mercerised cotton with methylene blue in the cold.

"When it is considered how varied are the circumstances and factors coming into play in these two dyeings, and that a gradual reduction in the coefficient of distribution is also noticed in numerous other instances, there will be no hesitation in according the above expression the dignity of a law, which, however, for reasons which cannot be argued out in detail here, only applies in its full extent to light medium colours. The aforesaid peculiarities of the dyeing process find their precise mathematical expression in the formula,

$$\sqrt[x]{\frac{Cb}{Cf}} = \mathrm{K}, \text{ which is a constant.}$$

"This is the law of distribution, and from this it will be seen that the value of the root sign x affords a measure of the affinity of the dye for the fibre, and naturally varies for different dyeings, being greater in proportion as the affinity of the dye-stuff for the fibre increases.

"From this law follows the practically important fact,

that the absorption of the dye, specially those that are not taken up readily, is primarily dependent on the volume of the bath liquor. It would, therefore, be more correct to apportion the weight of the dye taken to the volume of the bath liquor, and not, as is usually the practice, to the weight of the goods to be dyed."

Although this law undoubtedly holds good in some cases, there are a number of cases in which it does not express the relation, and it cannot therefore be taken as of universal application.

For perfect dyeing, in addition to the proportion of the dyeing materials being correctly co-ordinated to the material to be dyed, it is also essential that the material shall possess the necessary receptivity, and that it shall be prepared in such a manner that this quality shall be placed in the best condition to receive the dyeing material. The means by which this can be accomplished must therefore receive attention.

Receptivity of Wool.—In the case of wool there are a much greater number of substances which seem to have a direct affinity for the fibre than in the case of cotton, because the composition of the wool itself consists of a series of albuminoid bodies, all of which combine very readily with colouring matters, and the power of the fibre to absorb these, especially when properly cleared from all fatty matter, is very great, arising partly from its chemical and partly from its mechanical structure. This is an important matter, because before it is possible to dye any fibre there must be some means of introducing the dye-stuff into the interior of the fibre. When speaking on this point in the work on the cotton fibre,[1] it was pointed out how

[1] Bowman, *The Cotton Fibre in its Relation to Technical Applications*, p. 410, Macmillan and Co., London, 1908.

important a discovery was the power of dialysis which is possessed both by vegetable and animal membranes, and there is no doubt but that these laws play an important part in the absorbent power of the cell-walls in the wool fibre, and thus enable chemical reagents to be introduced within the fibre walls. Indeed, this appears to be the only solution which can be given, because the author found that perfectly washed wool, when placed in solutions which contain both "crystalloids" and "colloids," will absorb the former in far larger quantities than the latter, and thus render the process of mordanting, which is usually accomplished by some metallic salt which is a crystalloid, much easier than it would otherwise be.

Penetration of Dyes.—No materials are suitable for dyes except those which are soluble in either water or spirits. If the coloured bodies are insoluble they may be used as pigments, but not as dyes, because whatever may be the nature of the process by means of which the reagents are introduced into the fibres, it is quite clear that the state of division must be so small that the molecules can pass through the openings in the cell-walls, and it is impossible to conceive of any mere mechanical division, even though this is obtained by chemical precipitation, as being small enough to enable this to be accomplished. Such a molecular state would only be available to give a surface coloration by entanglement within the mechanical structure of the fibre, and could therefore be removed by mechanical means alone. The relation of the various dyeing materials to the wool fibre, so far as their union with it as permanent tinctorial agents is concerned, is similar to that of dyeing materials to cotton, except that there is a considerably larger number of these substances available in the case of wool, and that the majority of

these belong to a different class from those which are most largely used in cotton dyeing.

In looking at the three classes of reactions with dye-stuffs, given on p. 418, it was noticed that in the case of cotton, as might be expected from its chemically inert character, by far the largest number of dyeing processes depended upon the reactions included in the third or mechanical theory, and many in the second, while with the exception of such a dye as turmeric yellow very few belonged to the first. The aniline dyes, which in relation to wool belong to the first group, in their relation to cotton formerly belonged to the third, since they could not be fixed upon cotton until the yarn had first been mordanted with some such substance as tannic acid, although now mordanting of cotton is being largely superseded by the use of direct dyes of synthetical origin, which places them in the first group.

Even in the dyeing of wool, no very definite lines of demarcation exist between these various classes of dyeing material, because they seem to shade into each other by slow gradations.

It may, however, be generally stated that in relation to wool most of its reactions favour the first or chemical theory of dyeing, inasmuch as the dyes mostly used enter into chemical union and may be regarded as chemical compounds analogous to salts, in which the fibre acts sometimes as an acid and sometimes as a base, in the same way as such bodies as alumina and stannous oxide behave towards strong acids or bases. So, too, in relation to the acid and basic coal-tar colours, wool absorbs from each of them, from concentrated solutions, a maximum amount of colouring matter which have more or less simple molecular relations to each other. The same conclusion

may also be drawn from the fact that when wool is dyed in a solution of hydrochloride of rosaniline (magenta) the hydrochloride undergoes decomposition, and, while the rosaniline forms with the wool fibre an insoluble coloured compound, the whole of the acid remains unchanged in solution.

So also Hummel[1] states in regard to certain colouring matters of a marked acid character, such as the sulphonic acid azo colours, that the wool plays the part of a base. Since it cannot decompose the alkali salts of these azo colours, it will not dye with them unless the colour acid is liberated by the addition of a mineral acid to the dye-bath, and, if the free colour acid is of a different colour from its alkali salt, the dyed wool takes the colour of the salt and not the acid, which shows the basic action of the fibre and its union with the colour acid.

These reactions also indicate that, so far as wool is concerned, a classification of dyes may be made based upon their basic or acid properties, and this division, based upon chemical properties, illustrates certain fundamental principles in regard to dyeing. Alizarin and rosaniline, mentioned above, may be taken as two types of these different reactions, since they require to be combined with two substances of a different character if they are to form stable coloured compounds. The alizarin-red results from the union of alizarin with alumina, which is alkaline, and magenta from the union of rosaniline with hydrochloric acid. The alumina and other metallic oxides act as mordants to the alizarin, and the mineral or organic acids, such as hydrochloric or tannic acid, act as mordants with the basic dyes.

Cotton Dyeing.—It was noticed when treating of the dyeing of cotton that the structure of the fibre and its

[1] Thorpe's *Dictionary*, vol i. p. 702.

chemical character rendered it particularly suitable for the use of mineral dyes, which from their very nature have a very permanent character, such as Prussian blue, chrome yellow, or manganese brown, etc., which are merely chemical precipitates, differing in no respect from those which we throw down in the glass vessels in our laboratories, entangled within the cell meshes of the fibre; and that, when it became necessary to produce great permanence and brilliancy of colour, and to use those dyes which were originally obtained from vegetable sources, such as madder reds, formerly used in the production of the famous turkey-red colour, it became necessary to produce an artificial surface within the cell-walls to receive the colour, because it is impossible to dye the cotton fibre with it, so that the cotton fibre became simply a case or envelope to shield the artificially prepared and dyed surface.

One notable exception occurs in the case of indigo, which is a colour of vegetable origin, and which is more permanent upon cotton than upon wool, but a microscopical examination of the indigo-dyed cotton fibres showed that the method in which the colouring matter was united with the fibre clearly indicated that in the case of this dye, although of vegetable origin, it always acts in the same way as the mineral dyes—the union being far more mechanical than chemical, and the colouring matter being thrown down from the colourless indigo by the action of the oxygen, and mechanically entangled in the fibre meshes in the same way as the mineral precipitates.

It must be remarked, however, that these mineral dyes have now no place in cotton dyeing, except perhaps in regard to chrome yellow, as they are now almost entirely displaced by direct dyes, which give full shades without any mordant. These are generally prepared by diazotising

the bases and combining the products with amines or their sulphonic acids. These are represented by a whole series which yield almost any colour, such as Congo, Benzadine, Diamene dyes, etc.

Wool Dyeing.—Wool, on the contrary, has a great affinity for those colouring matters which are derived from the vegetable kingdom, and many of them play by far the largest part in all those dyeing processes where permanence of colour is required, and in modern dyeing the synthetic substitutes for these are used along with or without a mordant.

Wool appears to have a direct affinity, whatever this arises from, for the following colouring matters, and will extract them from their solutions without the use of any mordant, viz. all the aniline dyes, picric acid, indigo extract, cudbear, archil, and to a smaller extent those derived from the red woods such as brazil-wood, etc., and the yellow woods such as fustic.

In all these cases, although the wool will absorb and fix the colouring matter from the solutions, it will not do so equally in all parts of the fibre unless the very greatest care has been taken to secure that the wool is thoroughly cleansed from all mechanical and chemical impurities, and indeed it has been forced upon the author's attention, while experimenting in the laboratory, how absolutely essential the preparatory processes before dyeing really are, and the greatest success will always attend those dyers who make the thorough cleansing of the yarn or wool a matter of first importance. Time after time the author has seen defects in goods which he believes arose entirely from want of sufficient preparation, so that the dye-stuffs, whether requiring a mordant or not, could not either be evenly or permanently fixed, and were either removed or partially

discharged in the finishing of the goods. This leads the author to call attention once more to the great care necessary in the washing of the wool before spinning, and even before that to the necessity of using only such sheep washes and salves as will not injuriously affect the wool in after-chemical processes, because the use of these, and bad soaps, adulterated with all manner of unknown substances, are sure to interfere with the perfect dyeing of the wool, and can often never be entirely removed by the dyer.

Arsenic in Wool.—Here it may be noticed that arsenic always occurs in association with wool even in the natural state, and this it is almost impossible to entirely remove, as it evidently is a portion of its mineral structure. Although very widely diffused in nature, the arsenic in wool is generally derived from the dips which are used as protectives against parasites and into the composition of which arsenic largely enters, and its use is not only not detrimental to the health of the sheep but distinctly beneficial. It is true the amount is small, and no doubt a large portion, which is only mechanically associated, is removed by washing; but Thorpe gives the following as the result of analysis:—

	Arsenious Oxide in Mgrms. per Gram of Wool treated.
Wool from ewe (dipped with carbolic dip 15 months previously)	0·047
Wool from lamb (mother dipped shortly before its birth)	0·019
Wool from lamb (mother dipped with arsenical dip)	0·0005

Even wool after manufacture shows traces, as given below:—

	Arsenious Oxide in Mgrms. per Gram of Material treated.
Flannel from natural wool	0·005 to 0·009
Berlin wool (white)	0·037
Flannel (Welsh)	0·015
" (cream)	0·004
Wool vest (undyed)	0·011

This arsenic is, however, in too small quantity to affect the dyeing process.

Temperature of Dyeing.—Nearly all wool dyes are applied to the fibre at a high temperature, very frequently at the boiling point, 212° F., and, from the nature of the way in which the wool and admitted steam are related in the vat, frequently at a higher point than this. In looking at the action of heat upon wool it has been seen how deleterious this is when the lustre of the wool is to be preserved, and how much the sensitive and delicate surface of the epidermal scales is injured by it. The necessity for this seems to arise from the fact that certain of the associated fats are more soluble at a high than a low temperature; that the cell-walls being expanded by the heat are rendered more pervious to the colouring matter than when cold; and perhaps most of all that there is, as every microscopist who has examined fibres knows, a large quantity of air always enclosed within the fibre walls, which resists the entrance of any solutions and, until removed, prevents the osmotic action of the cell-walls, and the heat of the boiling water and the agitation occasioned by it materially assist the disengagement and escape of the air, and thus leave the passage for the entrance of the colouring matter free. Another important point to notice is the influence of temperature.

Temperature and Absorption.—Chemical action in

relation to the changes occurring in the dye-bath was calculated by Hood (*Phil. Mag.*, May 1878), from data obtained from Harcourt and Esson, to be proportional to the square of the temperature.

Mills and Rennie (*Soc. Journ. Chem. Ind.* vol. iii. p. 215) found some remarkable results by dyeing wool with rosaniline acetate. ·5 grms. of wool were dyed in 200 c.c. of a solution of the dye containing ·1 grm. per litre, with the following results:—

Temperature of Dye-bath.	Result.
36° F.	No colour deposited.
88° F.	Maximum ,,
178° F.	Very little ,,
212° F.	Fair amount ,,

It will be noticed that there is a sudden change at 178° F., as the colour seems to lose its attraction for the fibre, which they think was due to the increased solubility of the dye in the aqueous solution, and, therefore, the increased resistance to absorption; and the reverse action, again, above 178° F. may be due to the fact that basic dyes above this temperature, and at the boiling point rosaniline salts, are decomposed and the colour entirely destroyed if the action is prolonged. In dyeing with these colours the solution should not be too strong, and proportioned to the quantity of wool to be dyed, and the temperature about 112° F. seems to be the best and injures the lustre of the wool the least. Wool in practice is usually dyed in an acid bath, and gradually raised in temperature up to close on the boiling point. For colours such as alkali blue, the dyeing is usually in a neutral bath, and the acid used to develop the colour added at a later stage.

Distribution of Dyes.—In making an examination of

the wool fibres under the microscope, dyed with substantive colours such as the anilines, the author was particularly struck with the same peculiarity in wool which he noticed in cotton with these colours, viz. the very great evenness and diffusion which was manifested in the arrangement of the colouring material. It seems to make little difference what may be the special colour examined, for all the aniline colours seem to penetrate every part of the fibre; and although there are individual fibres which do not seem to absorb an equal amount of colour to the others with which they are associated, if they take any tincture whatever it is evenly diffused when compared with such a colour as indigo.

When examining a number of yarn dyed samples of wool, the author found that although the diffusion is wonderfully even on the surface of the fibres it does not always penetrate to the centre of the fibre, and when it does so the depth of shade is not so great as on the surface. He found also that different parts of the same fibre were unequally coloured, but the different parts were not separated from each other by any distinct divisions, but by slow gradations diffusing gradually into the lighter shades. When dyeing the fibres in small samples in the laboratory, he always found that if the wool was thoroughly cleansed and a sufficient length of time allowed to absorb the dye, when the fibres were examined, under even the highest powers, the colour was uniformly diffused through every part of the fibres where a cellular structure was distinctly visible; and even where it was not, and the fibres showed indications of kempy structure, the surface of the fibres was sufficiently stained to prevent the difference being noticed when reflected and not transmitted light was used. Fig. 76 gives an illustration of wool fibres dyed red with an

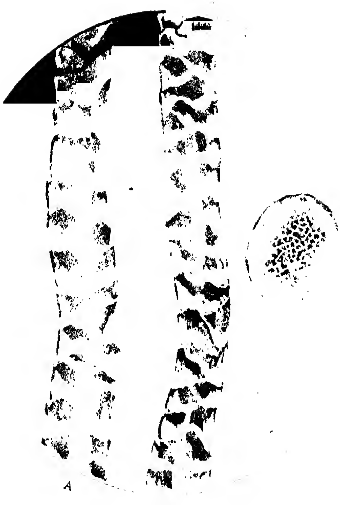


FIG. 76.—Fibres of Wool dyed with a Red Azo-dye, and viewed with transmitted light. × 430 diameters.

azo dye, in which the general diffusion of the dye over the whole surface of the fibre is seen, when viewed with transmitted light, but in some parts of the fibre the dye is deeper in shade than in others, and this is distinctly marked in the centre of the fibre A, while not so marked in the fibre B. In the section C the distribution of the dye is not so even as on the surface, but probably the mottled appearance on the surface of A arises from the light having, in passing through the fibre, to traverse areas of unequal colour, as seen in the section, which never appears to penetrate entirely to the centre. Some of the azo dyes, which yield all shades of colour, show a more even distribution than the red, and this is specially marked in the lighter shades. It may also be stated that with transmitted light the shades are much lighter than when the light is reflected from the surface and also the shade is rather different. In the red it is less crimson and in the azo-yellow, as seen in Fig. 77, it appears to be less of an orange-yellow, and more approaches a canary-yellow. The yellow shade is wonderfully even, and in the section at A it will be seen that the dye has in this case penetrated to the centre of the fibre, although there is an annulus of a deeper shade around the margin, but it is not so uneven as in the red. In both the fibres B and C the diffusion seems to be equally regular, but there is always a tendency to a deeper shade in all the dyes just at the base of the individual scales, as if larger masses of colour were retained just at the junction where the free margins of the overlapping scales occur.

Great advances have been made in synthetical dyes, and some of the yellows, blues, and scarlets produced by them are now as permanent as any of the similar shades derived from other sources. The very fact that it is possible to

produce by them so many shades, and that they are capable of such very easy molecular displacement, renders them equally liable to easy deterioration as reflecting surfaces. When the wool is imperfectly prepared for dyeing even these readily uniting colours will not be absorbed evenly; and, indeed, when the wool is perfectly prepared, the very great affinity of the fibre for the colouring matter becomes a difficulty, because those fibres which are most favourably situated, as when on the outside of the yarn or piece, will take up more than their share from the solution, and thus leave the others with less. Hence in the dyeing of these colours it is best to introduce the colouring matter at several times, so as to prevent the acquisition of too deep a shade by those fibres which from various causes are able to absorb it. So great is the affinity of wool for these colours, that when left for a sufficient time in the solution the fibres will remove and fix all the colour, leaving the original solution perfectly uncoloured, and in practice it is usual to introduce sulphate of soda, borax, alum, and various other substances along with the dye-stuff so as to modify the action and render it less energetic.

Pure Water.—It may not be out of place here to point out the great importance of using pure water for all dyeing purposes, because the impurities in the water, which often are very various, will introduce a series of imperfections into the dyeing of colours which cannot be overlooked when good and perfect work is to be obtained; for while, in the general sense of the term, the practice of dyeing is not under consideration here, it will be readily seen that with colouring matters which are so readily acted upon as the anilines, the presence even of small quantities of the sulphates, chlorides, or carbonates of lime or magnesia, or worse still of iron, or the presence

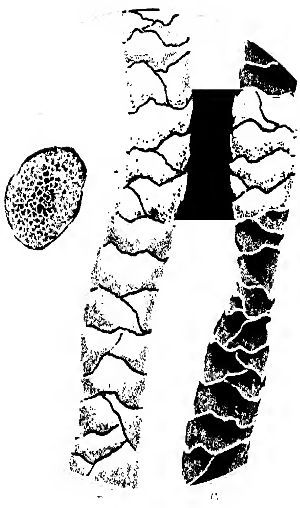


Fig. 77.—Fibres of Wool dyed with a Yellow Azo-dye, and viewed with transmitted light. × 430 diameters.

of the alkaline carbonates, such as potash or soda, will materially influence not only the shade of the dye but its diffusion and fixation within the fibre.

On no occasion has the author ever found the aniline colours to exist in a distinct molecular aggregation within the fibre walls, for whether the tint is dark or light, it is always marvellously diffused through the whole cell-walls, so that they retain their apparent translucency when subjected to transmitted light.

Indigo Dye.—This remark does not apply to all the substantive colours if indigo is to be included amongst them, because this colouring matter in itself can hardly be said to have a direct affinity for the fibre, since it is not soluble in its coloured condition either in water, alkali, or dilute acids, and hence cannot be introduced into the interior of the fibres; but it can be rendered soluble by the action upon it of nascent hydrogen, two atoms of which unite with two molecules of the coloured indigo and form a double molecule of a colourless body, known as a leuco compound, which is termed white indigo, and which is soluble in alkaline solutions, such as lime, soda, or potash, and can thus be introduced by diffusion into the interior of the fibres. When fibres which have been impregnated with this colourless indigo are dried out of contact with oxygen they appear to have acquired a yellow tinge, both examined by reflected and transmitted light, and the shade appears to be very uniformly distributed within the fibres; but when the fibres, after impregnation with this substance and before drying, are permitted to come into contact with oxygen, the double colourless indigo molecule is again broken up by the removal of the two atoms of hydrogen, and the two molecules of coloured indigo are precipitated within the constituent cells of the fibre.

This reaction may be represented by the following equation:—

$$\underset{\text{Colourless indigo.}}{C_{16}H_{12}N_2O_2} + \underset{\text{Oxygen.}}{O} = \underset{\text{Blue indigo.}}{2C_8H_5NO} + \underset{\text{Water.}}{OH_2}$$

In the indigo vat there is always, in consequence of the contact with the air, a quantity of the coloured indigo in a state of mechanical suspension, and always on the surface of the fibres as they are withdrawn from the vat a quantity of the colourless and coloured indigo adhering to the surface of the fibres, and consequently always a large quantity of surface coloration; and when indigo-dyed fibres are examined beneath the microscope, the dark masses of the non-crystalline indigo are seen adhering to all the surfaces of the fibre, and penetrating beneath the overlapping scales which cover them. Even when this surface coloration is removed, the appearance of the dye-stuff within the fibre is very different from that of the aniline colours. In some places it seems evenly diffused through the cell-walls, but when examined with high powers there is always a grained structure visible, as though the colouring matter itself was not chemically united with the substance of the fibre, but associated along with it in a mechanical form, yet so intimately that it is impossible to separate one from the other. The difference between the regular and transparent diffusion of the aniline and indigo is of course much more marked in some fibres than others, and even in the different parts of the same fibre; but the author cannot come to any other conclusion than that we must look upon indigo as more mechanically than chemically associated with the fibre, and that it owes its permanence of colour not so much to the chemical stability of its union with the fibre as to its

natural fixity of colour as a substance, and thus when enclosed within the fibre walls, by being thrown down as a coloured insoluble precipitate from a colourless solution, it is firmly retained there, and nothing but the destruction of the fibre can destroy it. The action of the dye upon the fibre is exactly the same even when synthetical indigo is employed, which has largely superseded the natural product. Fig. 78 represents wool fibres dyed with synthetic indigo, and in these the peculiarities of distribution noted above are clearly seen, and can be compared with those of the wool fibres dyed with the azo-aniline colours given in Figs. 76 and 77. Even when viewed with transmitted light the unevenness of the distribution of the colouring matter is evident in both the fibres A and C and also in the section B. The dye lies in patches on the surface, and specially near where the free margin of the scales touch the fibre in A and C; and in the section B the annulus of colour round the margin is specially dense, while the centre of the fibre is almost entirely uncoloured. In many fibres the diffusion is far less even in both cases. All vat or leuco dyes present a similar appearance, but in the case of logwood the dye is more even than with indigo. The union of the indigo with the wool fibre appears, however, to be more intimate than with cotton, notwithstanding which the indigo is more permanent on the cotton; but this seems to arise from the fact that from the nature of the cotton fibre, which has an internal cavity except when perfectly ripe, it can retain the coloured indigo in larger masses, and these resist the action of wear and tear better than the smaller molecular aggregations in the more complex wool. It appears, therefore, that we must regard the union of indigo with wool in a different light from that of the aniline colours, and consider that it probably stands

intermediate between those which require no mordant and those which are only mechanically associated. At the same time it is necessary to mention that in the case of thoroughly cleansed wool, the same as cotton, the author was never able, after once the wool had come in contact with any salt, such as the prussiate of potash, to remove the whole of this salt from the fibre by any means employed. This seems to indicate that there must be more than a mere mechanical retention within the fibre, for a part of the solubility seems to be lost, and thus the complete removal rendered impossible.

Mordant Dyeing.—Neglecting the aniline colours, however, the most important class of colouring matters which are used in the dyeing of wool are those which have no direct affinity for the fibre, and therefore require the use of mordants for the purpose of fixing them, while at the same time they exercise no deleterious action upon the colour. When treating of the mordanting of cotton it was seen that the mordants in use were very numerous, and consisted of metallic salts and various organic bodies, such as oil or albumin. In the case of wool the latter are never used, and the mordants are exclusively metallic salts, and mostly those of aluminium, chromium, iron, copper, and tin. These salts fulfil all the requirements of good mordants, because they are completely soluble in the water employed as the liquid menstruum, and yield when absorbed within the fibre an insoluble deposit which readily combines with the colouring matter; and they are capable of such even distribution through the fibre that they prevent the uneven appearance which always occurs without their use, even when the colouring matter used along with them has an affinity for the wool, by modifying and tempering the action.

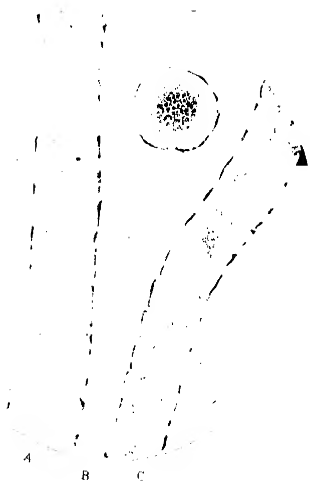


FIG. 78.—Fibres of Wool dyed with Synthetic Indigo, and viewed with transmitted light. × 430 diameters.

The salts of these metals which are used are various, and have mostly been arrived at as the result of practical experience; but as their action has been further investigated, good reasons can now generally be given from a chemical point of view why they should be used. Aluminium is generally used in the form of alum or alum-cake, chromium as the bichromate of potash or soda, iron as the protosulphate or nitrate, and copper as the sulphate. In tin the solutions most in use are the chloride, bichloride, and nitrate.

Those who are chemists will, in looking over this list, notice that most of these salts are of a very unstable character, in which the acid and base are united together by very feeble affinities, so that in the presence of the wool fibre, and especially at a high temperature, they are decomposed, and an insoluble deposit is thrown down within the meshes of the fibrous structure, which is generally either a subsalt of the metallic base, as in the case of the iron and tin compounds, or a hydrate, as in the case of the aluminous salts, or a mixture of the two. In the case of the bichromate of potash, which is one of the salts most largely used, the action as a mordant is different to all others because its constitution is different. "The metal which is deposited as a hydrate upon the wool is present in this salt as the acid, and not as the base, which is potash. Bichromate of potash may be represented as being neutral yellow chromate of potash in combination with dry chromic acid, thus:—

$$\underset{\text{Bichromate of potash.}}{K_2Cr_2O_7} = \underset{\text{Chromate of potash.}}{K_2CrO_4} + \underset{\text{Chromic acid.}}{CrO_3}$$

To obtain the full effect of the bichromate as a mordant sulphuric or formic acid is usually employed along with it,

although it can be employed without the acid. The whole or major part of the chromic acid is thus set free :—

$$\underset{\text{Bichromate of potash.}}{K_2Cr_2O_7} + \underset{\text{Sulphuric acid.}}{H_2SO_4} + \underset{\text{Water.}}{H_2O} = \underset{\text{Sulphate of potash.}}{K_2SO_4} + \underset{\text{Chromic acid.}}{2H_2CrO_4}$$

Chromic acid is a most powerful oxidiser, and acts energetically upon wool, and should therefore be used with caution. The wool furnishes the reducing agent, probably in the form of hydrogen, which acts upon the chromic acid, thus :—

$$\underset{\text{Chromic acid.}}{2H_2CrO_4} + \underset{\text{Hydrogen.}}{3H_2} = \underset{\text{Water.}}{2H_2O} + \underset{\text{Chromic hydrate.}}{Cr_2(HO)_6}$$

The chromic hydrate thus produced is deposited upon the wool as the mordant hydrate. A portion of neutral chromate of potash is also usually present in the fibre."[1] Mr. Jarmain also adds: "I have ascertained experimentally that it is not safe to use more that 3 per cent of the weight of the wool of bichromate, for if 4 per cent be used the colour becomes impaired, and if 12 per cent be used the wool cannot be dyed at all with logwood, and the curious effects of over-chroming are produced. These effects are due to the oxidising action of the chromic acid upon the wool. When a still larger quantity of bichromate is used along with the sulphuric acid, the wool is dissolved and a solution of chrome alum is obtained." To prevent the action of the chromic acid on the wool itself, restrainers such as tartaric and lactic acid are frequently employed.

Reducing Action of Wool.—It has already been seen, in speaking of the dyeing of cotton, that there is a curious reducing action of fibres upon metallic salts, and the same

[1] Cantor Lectures on Wool Dyeing. G. Jarmain, F.C.S., etc.

remarks apply also to wool. Whether or not the action is the result of the power of occlusion of a larger quantity of oxygen than is normally present, or the result of a catalytic action between the metallic salt and the fibres, is at present involved in mystery, but it may explain or at any rate may have something to do with the action by means of which some of the mordants are deposited and retained within the fibres, and the investigation of these obscure reactions may ultimately throw a new light upon some of the operations which at present are very imperfectly understood. In these cases, indeed, in which the mordant is oxidised within the fibre meshes, as when ferrous hydrate is changed into ferric hydrate by the action of the air, the reducing action of the fibres is sufficiently powerful to prevent or at any rate materially retard an entire change, and as a consequence the ferrous hydrate may be detected in combination with the wool months after the wool has been mordanted.

In speculating on what is the cause of the relation between the fibre and the mordant, the chief interest is in the fact itself as modified by the presence of the fibre; and it has often appeared to the author that we cannot form any correct judgment in regard to the matter by any study of the reaction between the substances used for mordanting and any decoctions of the dye-stuffs, such as is evinced by precipitates obtained by their mixtures, unless we take also into account the modifying action of the presence of the fibre itself.

While the mordants used in dyeing wool are almost exclusively readily soluble metallic salts, the dyes, apart from synthetical ones, are almost entirely decoctions of the colouring matters which are extracted from the various kinds of yellow and red woods, such as logwood or brazil-

wood, or of some of the colouring matter extracted from lichens or weeds.

The action of all these colouring matters is somewhat similar so far as their relation to the fibre is concerned, because, although they are capable of imparting colour to it, the colour is more or less transient and uneven unless the fibre has been previously mordanted. Of course the colour is varied by the different kinds of mordant and wood used, and since it is possible to obtain red, yellow, and blue, almost any variety of colour can be obtained by varying the proportions of each. As we are not considering the whole subject of dyeing, but only the relation of the fibre to the colouring matter, it may suffice to confine ourselves to the examination of the relation of one of these colouring matters alone, which may serve as a type of the rest.

Logwood Dye.—Undoubtedly the most important natural dye-stuff employed in the dyeing of wool is logwood and the colouring matter which is extracted from it. One important advantage of the use of logwood is that it dyes the vegetable as well as the animal matter, and this masks many defects which might otherwise be apparent. Logwood is principally obtained from Central America and the West Indian Islands, and is the wood of a tree named by Linnæus *Hæmatoxylon campechianum.* The large logs in which it is imported are ground into chips or raspings, and the colouring matter is extracted by the use of water or spirituous solvents, in the latter of which it is most soluble. The colour of the extract is a fine red, inclining towards violet or purple, and if left exposed to air becoming yellow, and finally black.

Like indigo, the colouring matter of logwood is capable of existing in two forms—hæmatoxylin, which is colourless,

and may be represented by the formula $C_{16}H_{14}O_6$; and a coloured body, hæmatein, which contains two atoms of hydrogen less, $C_{16}H_{12}O_6$. By oxidation on exposure to air, the hæmatoxylin is robbed of two of the hydrogen atoms and changed into hæmatein, and it is this body which is the colouring matter used in dyeing. An almost infinite variety of shades of colour can be produced by logwood alone, but this range is very much extended by combination with other dye-stuffs. When fibres which have been dyed with logwood are examined under the microscope they are usually dyed completely through, especially when well mordanted. If the fibre is broken up, the colour, whatever the shade may be, seems to penetrate into the interior of the constituent cells, so that there is no wonder that it is so largely used not only by itself but also to form a topping for other colours. The author, however, has found that all the fibres in a lock of wool do not seem capable of equally receiving the colour when subjected to exactly the same treatment for the same length of time. In the case of the coarser and more robust fibres, when the external scales are large and few, as generally found on the flanks of the animal, the colouring matter seems to act on the cellular mass within the fibre with greater readiness than the external scales. When the character of the scales is transparent, as in the case of the bright deep-grown English wools and the mohair wool, this resistance of the external sheath of the fibre to colour is of less importance than when the external scales are more opaque, as in the case of the alpaca fibre, because the coloured light from the deeper layers is transmitted through the outer sheath, and thus the general depth and regularity of the colour is not impaired. When, however, as in alpaca, the scales are more opaque, this resistance of the outer sheath is more

important, because the whole structure of the fibre is denser, and as the colouring matter is more topical it is more liable to removal by the application of surface friction or heat, and the goods acquire a shaded or faded appearance, and the less translucency of the scales prevents the transmission of the coloured light from the deeper seated layers.

This structural peculiarity ought always to be taken into account both in the dyeing and finishing of goods, because the colours are less easily fixed, and more easily disturbed, on all those fibres where the epidermal scales are large and dense, than where they are small and transparent. When these two fibres are mixed in the same fabric the treatment must always be in view of the former class.

When fibres of wool which have been dyed with these colouring matters are examined under high powers, it will be found that not only do the separate fibres exhibit great differences in the power which they seem to possess of absorbing the colour, but that the same fibres exhibit considerable differences in their various parts. This, probably, to a certain extent depends upon the nature of the cell-contents which are contained within the cells which constitute the fibre. Some of the cells are almost unaffected by the dye, while those immediately surrounding them appear uniformly dyed. When speaking on the nature of "kemps," it was pointed out that in some cases this solidity of structure commenced with isolated cells at first, and that these gradually increased until the structure was manifest in the whole thickness of the fibre; and it appears that in some fibres at least we have this solidity of structure appearing in isolated cells, and never proceeding beyond them. The better the class of wool the less irregularity there seems to be not only in the mechanical

structure of the respective fibres as a whole, but also in that of their component parts, and it cannot be too strongly urged that in all cases where great perfection of dyeing is desired there should be special attention paid to the classification of the wool out of which the goods are made, for the perfection of the whole can only be attained through the perfection of the various parts.

Finishing.—Before passing to the conclusion of the subject it is not inappropriate to refer to the relation of the wool fibre to the finishing process, to which most goods are subjected before being ready for the merchant's counter.

This process varies very much with the class of goods and the nature of the finish which is required, and this difference in requirement necessitates a considerable variation in the mechanical and chemical processes to which the goods are subjected.

As a rule, the chief agents employed in finishing are heat, moisture, and pressure, along with a certain and variable amount of stretching or strain, both lateral and longitudinal. Sometimes a milling or fulling process is introduced so as to shrink and mat or felt the fibres, to give increased substance and body to the goods. In addition to this for certain classes of effect it is necessary to crop the surface, so as to remove the superfluous fibre mechanically, or else to singe away this fibre by the passing of the surface over gas flame or heated copper plates.

Action of Pressure on Wool.—When speaking of the relation of the wool fibres to longitudinal strains, we might have also considered the action of pressure upon them, but forbore to do so until we had considered the action of heat and chemical reagents, because when subjected to these two influences their behaviour under

pressure is modified, and this plays an important part in the finishing process. When a fibre is subjected to the influence of moisture the curl is increased, arising from the unequal expansion of the component cells; but if subjected to longitudinal strain when in the moist condition, and permitted to dry while thus elongated, the curl is entirely removed, and a permanent set or fixation of the straight fibre occurs, accompanied by a permanent loss in elasticity. In the same way, if the wool fibre is subjected when in the natural condition to lateral pressure, the natural elasticity of the cortical part enables much of the original form of the fibre to be recovered when the pressure is removed. At the same time, if the pressure is long-continued, the fibre becomes more or less flattened, so that the section of the fibre changes from a rounded oval to a flattened ellipse. This is always accompanied by an increase in the lustre of the surface of the fibre, because all the component parts are flattened down. Thus, the dispersion of light from the surface is avoided, and the rays are thrown off in sheets as from the surface of glass or polished metal. When fibres are heated, especially along with moisture, the albuminoid cells are softened, and thus rendered non-elastic and plastic, so that they are easily altered in form and flattened by the pressure. If permitted to dry under the pressure, the flattening becomes permanent. The author examined a number of fibres under the microscope after being subjected to various degrees of pressure between both hot and cold plates, and both when dry and moist. The difference in form was quite apparent. When subjected to cold pressure the time required for alteration in form was very much longer than when hot and moist. In the latter case, the fibres could be changed by sufficient pressure into flattened ribbons,

and all traces of the epidermal scales obliterated. This was always accompanied by a considerable increase in the lustre, even when the original lustrous surface of the scales had been impaired by the moisture and heat, before subjecting to pressure—the heat, moisture, and pressure removing the pitting of the surface, and thus restoring its reflecting power. Upon this action depends the production of lustrous surfaces by the hot-pressing of goods after subjection to moisture, as well as the setting of goods to a certain width and length. It will, however, be easily seen that even in this case, although it is possible partially to restore the lustre of the fibre, it is not possible to do so to the same extent as it can be accomplished when the smooth lustrous surface of the fibres has not been impaired.

Cleanliness.—It is essential to point out how absolutely necessary it is to take the greatest care in the cleanliness of all the rollers, plates, and every part of the finishing machinery, because, when the fibres, especially when dyed light and delicate shades, are brought into close contact with the pressing surfaces they are far more easily acted upon than is generally supposed. The author has known of many cases where defects in goods have been traced to the effects produced by various reagents which have been left upon the mill boards by the goods for which they had previously been used.

The general principles upon which all manufacturing processes which depend upon the transforming power of machinery are based are now probably fixed for all time. Any advance which can be made will depend far more upon attention and improvement in small details than in a complete revolution of the method of manufacture. Technologists can only be guided in their search after

improvement by a much more thorough knowledge of the exact nature of the materials with which they have to deal that they at present possess, and the author shall at least feel that his efforts and time have not been wasted if they have in any measure contributed to this end. There is probably more to learn chemically than mechanically, but this knowledge is more difficult to acquire. It cannot now be obtained by lucky guesses. The surface soil of the chemical field which lies open to the light of heaven has been well surveyed, and yielded rich results; but the knowledge now to be obtained lies beneath, and nothing but a thorough acquaintance with the great laws of chemical and organic structure will enable us to penetrate the great secrets of nature.

CHAPTER XV

METHOD OF ANALYSIS AND DETECTION OF VARIOUS FIBRES

ALTHOUGH this volume deals exclusively with wool, it is often necessary to be enabled not only to detect the difference between wool and cotton and other vegetable and animal fibres, but also between the various kinds of wool and vegetable fibres which are closely allied to cotton, and which, although different in structure, are mostly impure or ligno-celluloses derived from the bast or inner bark of the plant stem or from the leaves, and are not single-hair cells. Also, now that cellulose is being so largely used in the manufacture of artificial silk or lustra-cellulose, it is often important to be able to say, or decide, the particular form of the cellulose employed in their formation, *i.e.* whether the fibres are derived from nitro compounds, pure cellulose, or mixed in origin, as when associated with gelatine or dissolved silk, and woven along with wool.

In determining these various points there are now a number of methods employed which enable all these various questions to be very easily decided, and a complete analysis of any fabric containing mixed fibres or any mixture of fibres can thus be made. As a rule, in examining any

mixture of textile fibres for commercial purposes, it is only necessary to distinguish between wool and other animal fibres and cotton, flax, jute, hemp, and ramie in vegetable fibres, and silk, cultivated, wild, and artificial, as these are almost all the fibres in general use.

The means employed are of two kinds—

1. *Mechanical*, in which the specific differences in structure, as revealed under the microscope, are seen; and

2. *Chemical*, in which the distinctive colour and other reactions, when treated with various reagents, are employed, or the variation in solubility or degrees of solubility in different reagents. Also the difference in degree of inflammability or behaviour when subjected to various degrees of heat.

1. *Mechanical Analysis.*

This is specially valuable when the fibres are in a perfect condition, and have only been associated together by the ordinary mechanical mixture and arrangement, as in the spun thread or woven fabric.

It is also specially valuable and applicable when the fibres have been dyed all one colour, or even different colours, which have not altered the mechanical structure of the fibre, as is mostly the case in textile fabrics.

When the fibres are placed under the microscope and examined, especially with transmitted light, and with powers varying from 20 to 500 diameters, which is well within the range of any ordinary cheap yet reliable microscope, the following distinctions are usually clearly visible:—

(*a*) *Cotton* presents the appearance of twisted collapsed ribbons, with more or less thickened edges, and exhibiting a wrinkled surface and a central cavity or lumen with cloudy and pith-like deposits. If the yarn has been fully

mercerised, the general character of the fibres is more robust and full, with less characteristic twists in them. The general nature of the cotton may be ascertained by comparison with Figs. 1 and 2 in Chapter II.

(*b*) *Flax, Hemp, and Jute.*—The general appearance of Flax is given in Fig. 3, Chapter II. The fibres always consist of a series of cells united together longitudinally, and usually thickened at the point of juncture with a node or ring, which adds strength and rigidity to the fibre. The length of the cells in proportion to their diameter and the number of nodes on the fibre differ greatly in various qualities of flax, and the general appearance is also similar in hemp and other bast fibres; but in jute, which is also a bast fibre, the nodes are generally absent, although the point of juncture of the multiple cells is quite apparent by distinct constrictions in the central cavity, and in many cases an actual juncture of the cavity walls. The ends of all these fibres are pointed, and the cross-section of the fibres polygonal, except at the point, which is usually round.

(*c*) *Wool.*—The wool fibre is easily distinguished under the microscope, and a typical fibre is shown in Fig. 15, Chapter IV. The fibre is always of a more or less cylindrical form, and not twisted like cotton, or flattened or polygonal in section like the bast fibres. It is always covered on the surface with rings of scales of more or less irregular form, with fine, smooth, or imbricated edges, which are always directed towards the point of the fibre. They differ very much in form and regularity, and also in size, depending upon the diameter of the fibre, and the number of the rings in a given length of the fibre also varies. Usually also there are indications of a curl or curvature in the fibre, and these peculiarities are always distinctive and enable it

Reagent.	Cotton.	Flax.	Hemp.	Jute.
Ammonia solution	...	...	Yellow or violet	...
Chlorine water	Bleaches	Bleaches	Yellow-brown	Violet on addition of ammonia
Cupra-ammonium solution	Blue solution	Blue solution	Blue solution	Blue solution
Cupric sulphate	...	...	...	...
Iodine solution	Yellow	Yellow	...	Light brown
Iodine and sulphuric acid	Blue	Blue	Green	Yellow to brown
Iodine and zinc chloride	Deep violet	Violet	Violet	Brown
Lead acetate	...	...	...	...
Mercuric nitrate	...	...	...	...
Nitric acid	...	...	Yellow	...
Picric acid	...	...	...	...
Potash (caustic) solution	Yellow	Brown	Brown	Brown
Silver nitrate	...	...	...	...
Soda (caustic) solution	Yellow	Brown-yellow	Brown	Brown
Stannic chloride	Black	Black	Black	Black
Sugar and sulphuric acid	...	...	...	...
Sulphuric acid	Dissolves	Dissolves dark colour	Dissolves dark colour	Dissolves
Zinc chloride	Dissolves yellow	Dissolves yellow	Dissolves	Dissolves

TABLE OF REACTIONS WITH

Dyeing Material.	Cotton.	Flax.	Hemp.	Jute.
Acid dyes in general	...	...	...	...
Alpha-naphthol and sulphuric acid	Red or violet	Red or violet	Red	Red
Cochineal tincture	Light red	...	...	Red
Diphenalimene and sulphuric acid	...	...	...	...
Fuchsine solution	...	...	...	...
Madder tincture	Yellow	Orange	Reddish	Reddish
Mikado yellow	Dyed	Dyed	Dyed	Dyed
Thymol and sulphuric acid	Violet	Violet	...	...

The difference between mercerised and unmercerised cotton is easily detected by using
Technical College. If the two cottons are immersed in a solution of zinc chloride, 100 cc.
solution of iodine in potassium iodide has been added, the ordinary cotton remains white,
colour acquired measures the degree of mercerisation to which the cotton has been subjected.

Ramie.	Lustra-Cellulose.	Wool and Hair.	Silk.	Gelatine Silk.
...	...	...	...	...
...	...	Yellow	Yellow	Yellow
Blue solution	Blue solution	Swells	...	...
...	...	Black	Violet	...
...	Yellow	...	...	...
Dull blue	Blue	...	...	...
Dull violet	Blue violet	...	Yellow	Yellow
...	...	Black alkaline solution	...	...
...	...	Red to brown	...	...
...	...	Yellow	Yellow	Yellow
...	...	Yellow	Yellow	Brown-yellow
Brown	Yellow	Dissolves	Dissolves	Dissolves
...	...	Violet to brown	...	...
Light brown	Yellow	Dissolves	Dissolves light red	Dissolves
Black	Black	...	...	...
...	...	Rose red	Rose red	...
Dissolves	Dissolves	Dissolves when hot	Dissolves when hot	Dissolves when hot
Dissolves	Dissolves yellow	Dissolves slowly	Dissolves	Dissolves slowly

VARIOUS DYEING MATERIALS

Ramie.	Lustra-Cellulose.	Wool and Hair.	Silk.	Gelatine Silk.
...	...	Dyed	Dyed	Dyed
Red	Red	Reddish-brown	Yellow-brown	Brown
Reddish	Red	Scarlet	Scarlet	Scarlet
...	Blue silk collodion	...	...	...
...	...	Red	Red	Brown
Reddish-brown	Yellow	...	...	...
Dyed	Dyed	...		...
...	Violet	...		...

the test first pointed out by Prof. Julius Hübner of the Manchester Municipa
of solution containing 93·3 grammes of the zinc chloride, to which two drops of
while the mercerised cotton takes a dark navy-blue colour. The depth of th

at once to be differentiated from silk and all vegetable fibres.

(*d*) *Hair* differs in appearance from wool, inasmuch as though it is usually covered with similar scales on the surface of the hair, they are always more closely adherent to the shaft of the hair, and the edges are not turned outwards. Fig. 61, Chapter XII., called Mohair, gives an illustration of the fibres or hairs from the Angora goat, and Fig. 16, Chapter V., shows the appearance of several different hairs. Alpaca, vicugna, Cashmere goat's hair, all closely resemble each other and mohair in having the scales more closely adherent to the shaft of the hair than in the true wools. The hair of almost every separate class of animals has distinctive features, either in the form and arrangement of the surface scales or the internal cells, and these will be separately treated in a future volume.

(*e*) *Silk*, which is a consolidated gum exuded from the glands of the silk-worm, has various appearances as derived from wild or cultivated worms. The cultivated silk, derived from the mulberry silk-worm, is shown in Fig. 4, Chapter II., and has the appearance of a double strand of a clear, semi-transparent, lustrous, continuous fibre, with usually a rounded section in each of the strands when the cementing gum has been removed, but the form of section differs slightly, depending on the position of the fibre in the cocoon. The wild silks always exhibit a fibre which is much flatter and irregular in section, and the fibres are usually much more striated on the surface in the direction of their length and larger in diameter than cultivated silk.

(*f*) *Artificial silk* or *lustra-cellulose* is, in appearance, under the microscope, very similar to silk, but it does not exhibit the double strand of the cultivated silk, or the flattened and

striated appearance of the wild silk, and the difference is better disclosed by chemical than microscopical analysis.

2. *Chemical Analysis.*

Apart from the use of reagents, which give distinct reactions with the various different fibres, there is a very ready method of distinguishing between fibres of vegetable and animal origin, viz. by the way in which they burn when a light is applied to them.

Vegetable fibres when dry all ignite readily and burn with a comparatively bright, smokeless, and odourless flame, and leave very little ash. If the flame is extinguished before the whole of the fibre or thread is consumed, the vegetable is burnt off sharply at the end, and leaves a blackened or carbonised edge where the burning ceased.

Animal fibres, even when dry, and unless containing an amount of extraneous fat or oil, are more difficult to ignite, and unless the mass is large, the flame will frequently go out if the fibre is held horizontally, although, if held vertically, and lighted at the bottom, it may continue to burn without a fresh application of the light. The flame is usually more or less dull and lifeless, and burns slowly, with emission of a disagreeable empyreumatic odour, resembling the smell of burning feathers, and when extinguished the burnt edge is not clear and sharp, but fused into a rounded bead-like form, which retains the odour and feels sticky if crushed between the thumb and fingers. Vegetable fibres, when soaked with any mineral acid and dried, and then subjected to a dry heat, readily become charred and fall into dust, as in the process of carbonising described in Chapter XI., by means of which all vegetable matter can be removed from wool or other animal fibres which are unaffected by such strength of acid or acid salts.

Alkalies have an exactly opposite effect, and while they

readily dissolve animal fibres, have comparatively little effect on vegetable fibres, especially when the solution is not very strong. Usually all that is required by analysis is to remove the vegetable from the animal fibre, which is the more valuable, and not the reverse. When various animal and vegetable fibres are mixed and undyed, or after removal of the dye by bleaching, they give coloured reactions with various chemical reagents and solutions of colouring materials, and the tables given on pages 454 and 455, which have been carefully compiled from a number of sources, give these characteristic reactions, which are frequently of service in distinguishing between them.

GLOSSARY

OR, EXPLANATIONS OF SOME OF THE TERMS USED IN THIS WORK

Abnormal. An irregular growth or occurrence.

Absorption bands. The dark bands observed with the spectroscope when light is passed through any medium which destroys or absorbs a portion of the vibrations.

Albumin. Matter possessing the same properties as the white of an egg.

Albuminoid. Matter similar to albumin, but slightly differing from it in some of its reactions, such as casein and fibrin.

Aldehyde. A class of organic compounds intermediate between alcohols and acids.

Alizarine. The red colouring matter of the madder root; now prepared from coal-tar.

Alkaline ley. A solution of an alkaline salt.

Alpaca. The hair of the Alpaca goat.

Analysis. The breaking up of a substance into its simplest constituents, so as to determine their qualitative or quantitative relations.

Anastomosing. Crossing and re-entering at irregular intervals.

Anhydrous. Containing no water or elements of water in combination.

Aniline. An aromatic base occurring in coal-tar and similar products of the distillation of nitrogenous bodies, usually prepared from the benzine of coal-tar.

Archil. A purple colouring matter obtained from certain species of lichens.

Areolo-fibrous. Fibrous tissue with large irregular meshes.
Aromatic. Possessing a pleasant odour.

Bombycidæ. The family of insects of which the silk-worm is the early stage.
Britch. The extremity of the fleece at the tail end of the sheep or goat.
Brokes. Short locks of wool found on the edge of the fleece in the region of the neck and belly.

Callosities. Hard hoofs on the surface of the skin.
Cap spinning. Spinning by means of a steel cap placed mouth downwards over the spindle instead of a flyer.
Carding. The process of drawing the wool through fine wire teeth fixed upon rollers revolving at different speeds.
Case. To separate fleeces of wool into their various qualities.
Cellulose. The chemical substance of which the cell-wall in plants is composed.
Chromatic. Relating to coloured light.
Cocoon. The envelope of silk thread in which the silk-worm encloses itself when in the pupa state.
Colloid. A substance which will not crystallise.
Colloidal. Possessing the property of a colloid.
Combing. The process of drawing wool through the teeth of a comb either by hand or machine.
Convex. Curved outward like a bow.
Corium. The lowest layer of which the skin is composed.
Cortical. The cellulo-fibrous part of the hair structure.
Cots. Matted locks of wool forming a hard felt in the fleece.
Counts. The number given to any yarn according to the number of hanks in a pound.
Cow-tail. The coarsest hair at the tail end of the fleece.
Cross. To mix the breed by coupling two sheep possessing different properties.
Crystalloid. A metallic or organic substance which has the power of crystallising.
Cudbear. A colouring matter obtained from certain species of lichens.
Cuticle. The scarf skin or outermost layer of the skin; also any thin membrane.

Denticulated. Having teeth like a saw.

Dermis or derma. The deeper skin lying beneath the *Rete mucosum.*

Desiderata. Some things specially to be desired.

Dialyser. A membrane which possesses the power of allowing certain substances to pass through it, while it rejects other substances in the same solution.

Dialysis. The method of analysis by means of a dialysing membrane.

Diameters. When applied to microscopy signifies the number of times that a linear inch is magnified by the eye-piece and object-glass in use.

Differentiation. The setting apart of separate organs for the performance of specific functions.

Diffraction grating. A set of closely ruled lines for the purpose of decomposing white into coloured light.

Dissociation. The breaking-up of compounds into their constituents.

Drawing A process which arranges the fibres in parallel lines by passing through rollers running at different speeds.

Electric arc. The space occupied by the light between the poles of an electric light or battery.

Eliminate. To separate from or remove out of anything.

Empyreumatic. A pleasant pungent odorous smell of burning.

Emulsion. A thick solution as of soap in water.

Endochrome. The coloured substance within animal or vegetable cells.

Environment. The surrounding of any creature or thing.

Epidermal. Relating to the outer skin.

Epidermis. The outer layer or skin.

Epithelial. The lining membrane of any cavities within the animal body.

Excrescence. A growth upon the surface of any body.

Eye-piece. The top part of the microscope to which the eye is applied, and which can be removed to increase or decrease the magnifying power.

Ewe. A female sheep or goat.

Fellmonger. One who deals in skin wool, or removes the wool from the hides or skins before tanning.

Felting. Matting or entangling by motion and pressure.

Fenestrated. Having regular lozenge-shaped openings like the woodwork of a veranda or glass in a cathedral window.

Fibrillæ. Small fibres which build up the larger fibrous tissues.

Fibroin. One of the substances of which silk is composed.

Finishing. The process of setting and giving a proper surface to goods after the manufacture and dyeing are concluded.

Fleece. The pelt or mass of wool removed from the sheep by the process of shearing.

Fly spinning. The process of spinning on to a bobbin by means of a flyer.

Fœtal. Relating to the fœtus.

Fœtus. The young of a mammal before birth.

Follicle. The involuted sac or bag which contains the hair or wool within the skin.

Frame. A machine which carries the rollers and accessories for spinning or doubling by means of a flyer, cap, or ring and traveller.

Fulling. The process of cleansing and shrinking cloth by means of moist heat and pressure.

Fundamental. That which lies at the base of any object or operation.

Fustic. The wood of the *Morus tinctoria*, a tree growing in the West Indies, and which yields a yellow dye.

Gelatine. A substance allied to albumin, which forms the basis of animal tissues.

Gossypium. The generic name for the cotton plant.

Graduated. Having regular divisions like the dial of a clock or the surface of a measuring rule.

Half-bred. A cross between two different classes of sheep.

Halogen. A substance which by combination with a metal forms a haloid salt, such as common salt.

Hank. In worsted, 560 yards wound on to a 36-in. reel; in cotton and silk, 840 yards on a 54-in. reel.

Hask. Dry and hard, or unpliable.

Histology. The science which treats of the structure of organic tissues.

Hog or hogget. A sheep before its first shearing.

Homogeneous. Uniform in structure throughout.

Imbricated. Lying over each other like tiles or slates on a roof.

Incinerated. Burnt to ashes.

Infra-red. Beyond the red portion of the spectrum.

Inspissated. Dried up.

Iridescence. A play of colours like those seen on mother-of-pearl.

Kemps. Fibres of wool possessing no cellular structure.

Lachrymal sinuses. Glands in the corner of the eyes.

Laminated. Built up in layers like leaves of a book.

Lea. The seventh part of a hank; in worsted, 80 yards; in cotton and silk, 120 yards.

Ley. A solution of any substance, but specially used for alkaline solutions.

Linaceæ. The generic name for the class of plant from which linen is derived.

Litmus. A blue pigment derived from various species of lichens, which changes to blue on the application of acids.

Lixiviated. Dissolved out in water.

Logwood. The wood of the tree *Hæmatoxylon campechianum.*

Lorications. Having a scaly structure like the back of a crocodile.

Luminiferous ether. The ether which forms the physical basis or mechanism of light.

Lymphatic vessels. The vessels which convey a colourless fluid called lymph within the animal body.

Madder. The plant from the root of which alizarine was formerly derived.

Malpighii. Named after Malpighi the discoverer.

Malvaceæ. The generic name for the class of plants to which the marsh mallow belongs.

Matching. A quality of wool in the best part of the fleece.

Medulla. The pith or central axis of a stem or fibre.

Merino. A breed of sheep originally confined to Spain.

Meteorological. Changes dependent on the atmosphere, such as rain, snow, or wind.

Micrometer. A machine for measuring minute quantities of linear space.

Microscope. An instrument for magnifying objects.

Middle-woolled. Intermediate between long and short woolled sheep.

Millimetre. The thousandth part of a metre, ·03939 of an inch.

Milling. The process of thickening cloth by beating or pressure.

Modification. Changes produced in an animal or plant by slow degrees.

Mohair. The hair of the Angora goat.

Molecule. The smallest portion of a compound substance in which its properties can inhere.

Monochromatic. Only possessing one colour.

Mordant. A substance used to fix or intensify the colour of a dye.

Mousseline-de-laine. A fine fabric produced from wool.

Mule. A machine in which the spindles are placed upon a carriage which draws out from the rollers when the yarn is spinning and returns to them when the yarn is being wound on to the cop.

Mule spinning. Spinning yarn on a mule in place of a spinning frame.

Nascent. The state of activity of a substance when first set free from combination.

Nitrogenised. United or associated with nitrogen.

Normal. The usual or ordinary condition of anything.

Nucleated. Possessing a nucleus.

Nucleus. The centre from which germination commences.

Object-glass. The small compound lens which first receives the light in a microscope.

Objective. A short name for the object-glass.

Pack. A measure of weight in wool, usually 240 lbs.

Papillæ. Small raised paps or protuberances.

Papillary layer. The third layer of which the skin is composed, forming the highest layer of the dermis.

Pellucid. Clear or translucent.

Picric acid. Called also trinitrophenic acid. An organic acid produced by the action of nitric acid on phenol and other organic substances.

Pigment. A coloured paint, as distinguished from a dye.

Polarised light. A ray or rays of light, in which all the luminous vibrations are either in one plane or in two planes at right angles to each other. Circular or elliptical polarised light is where the plane or planes of polarisation are rotating round the axis of the ray in a circular or elliptical form.

Polygonal. A figure having many sides.

Precipitated. Thrown down in a flocculent manner from solution by a chemical reagent.

Prism. A triangular-shaped piece of glass used to analyse light into its constituent colours.

Protein. A nitrogenous compound, formerly supposed to be the base of albumin and other allied bodies.

Protoplasm. The primitive matter which forms the structure of cells and is the physical basis of life.

Ram. A male sheep.

Rationale. The reason or cause why.

Reagents. Chemical substances used to act upon other substances as tests for their nature.

Reducing agent. Any agent which deprives another of oxygen.

Reflex action. The action caused on one part of the system by a change produced in another part which acts on the nervous system.

Refrangibility. The degree of bending which any ray undergoes in passing through a prism.

Rete mucosum. The second layer of which the skin is composed, lying immediately below the scarf skin.

Retina. The sensitive part at the back of the eye upon which the impression of objects is received.

Ring spinning. Spinning by means of a ring and traveller in place of a fly or a cap.

Rules of thumb. Rules acquired by experience only.

Say cast. The coarsest part of the fleece at the tail end of the sheep.

Scroop. The peculiar noise made by silk when squeezed in the hand.

Sericin. A chemical substance of which silk is in part composed.

Serrated. Possessing teeth like a saw.

Single yarn. Yarn with only one strand or thread.

Sorter. One who sorts or divides wool into its various qualities.

Sorting. Dividing wool into its various qualities.

Sorting-board. The table on which wool is sorted.

Specialist. One who devotes attention to one subject or branch of knowledge alone.

Spectroscope. An instrument for examining light when passed through a prism.

Spectrum. The coloured band of light produced by passing white light through a prism or reflecting it from a fine ruled surface.

Spinnaret. The gland or opening in the body of a silk-worm through which the silk gum is exuded.

Staple. The lock of wool or hair which is formed by the aggregation of fibres in the fleece.

Stapler. A merchant who buys wool from the farmer and sorts it into its various qualities for the manufacturer.

Sudoriparous. Relating to the glands which exude the sweat or perspiration from the skin.

Suint or yolk. The fatty secretion from the skin of the sheep which is always associated with the wool.

Tannin. An astringent substance found in oak and other barks.

Technology. The science of the application of science or art to manufacturing industry.

Toppings. The dirt and accumulation of clay, etc., found on the skirts of the fleece.

Translucency. Partial transparency, as in the case of horn.

Tubercle. A small tube or duct.

Tumefied. Shrivelled into a carbonaceous mass by the action of heat.

Turmeric. A yellow colouring matter obtained from the root of *Amomum Curcuma*, a plant found in India and Java.

Twiner. A machine for doubling similar to a mule, as distinguished from a frame.

Twist. The turns or revolutions round the axis put into thread.

Twofold yarn. Yarn having two strands or threads.

Ultra-violet. Beyond the violet rays in the spectrum.

Water of hydration. The water which forms an integral part of the structure of a body.

Wether. A sheep after the first shearing.

Woollen. Made of woollen, as distinguished from worsted.

Wool-stapler. A wool merchant.

Worsted. Yarn in which the fibres of the wool are laid in a parallel direction before twisting.

Wrap reel. A machine for winding yarn off cops, or bobbins, or hanks, and measuring the length of the yarn.

Yarn. Fibre when spun into thread.

Yarn-tester. A machine for testing the strength of yarn.

Yolk or suint. The fatty secretion from the skin of the sheep which is always associated with the wool.

INDEX

THE END

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